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ANALYSIS OF CENTRAL TOTAL ENERGY SYSTEMS AT MILITARY FACILITIES--ETC(U)
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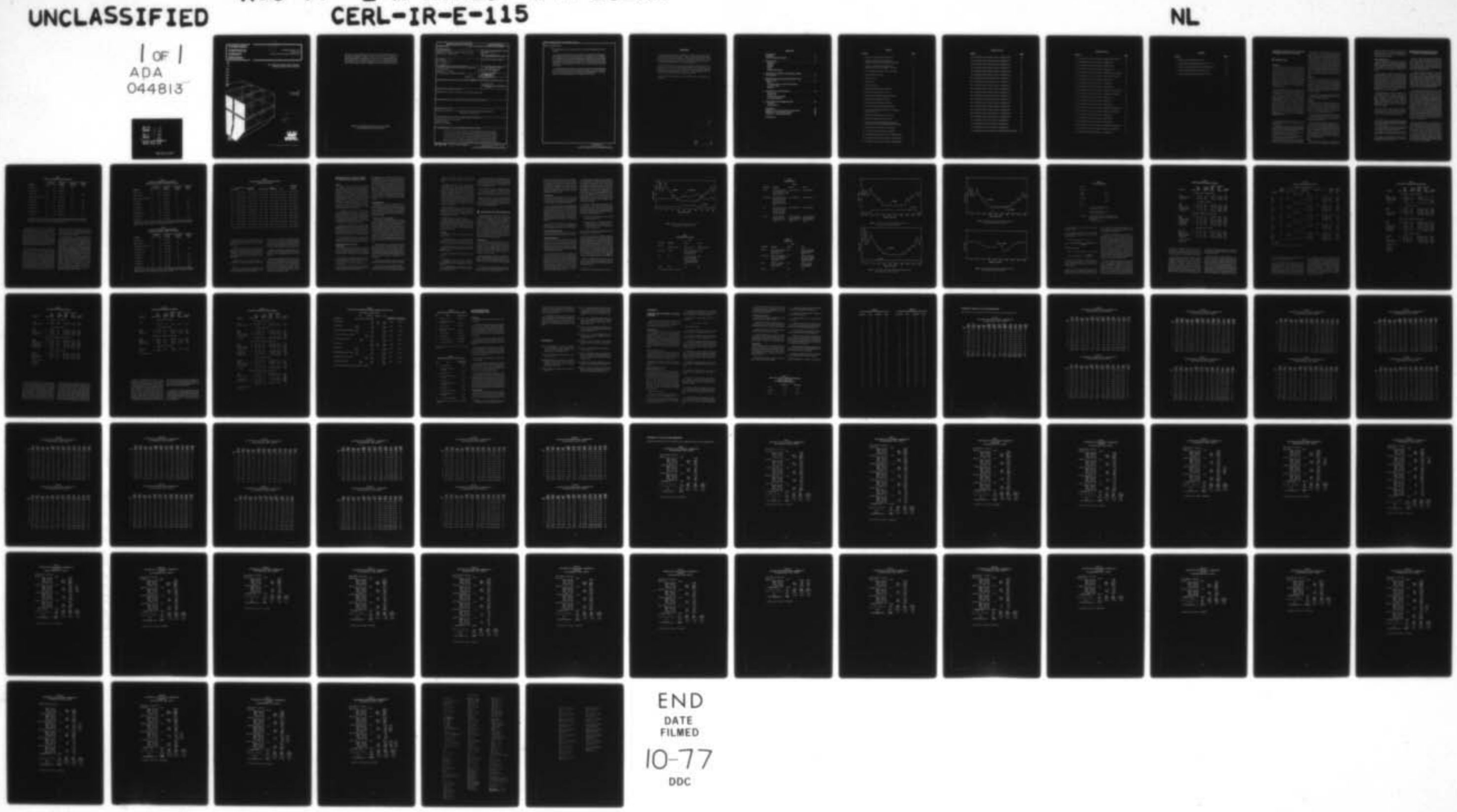

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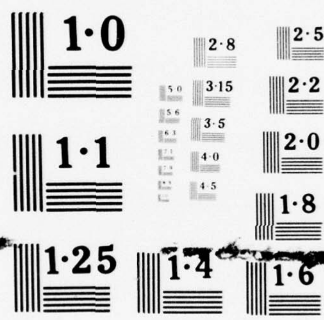
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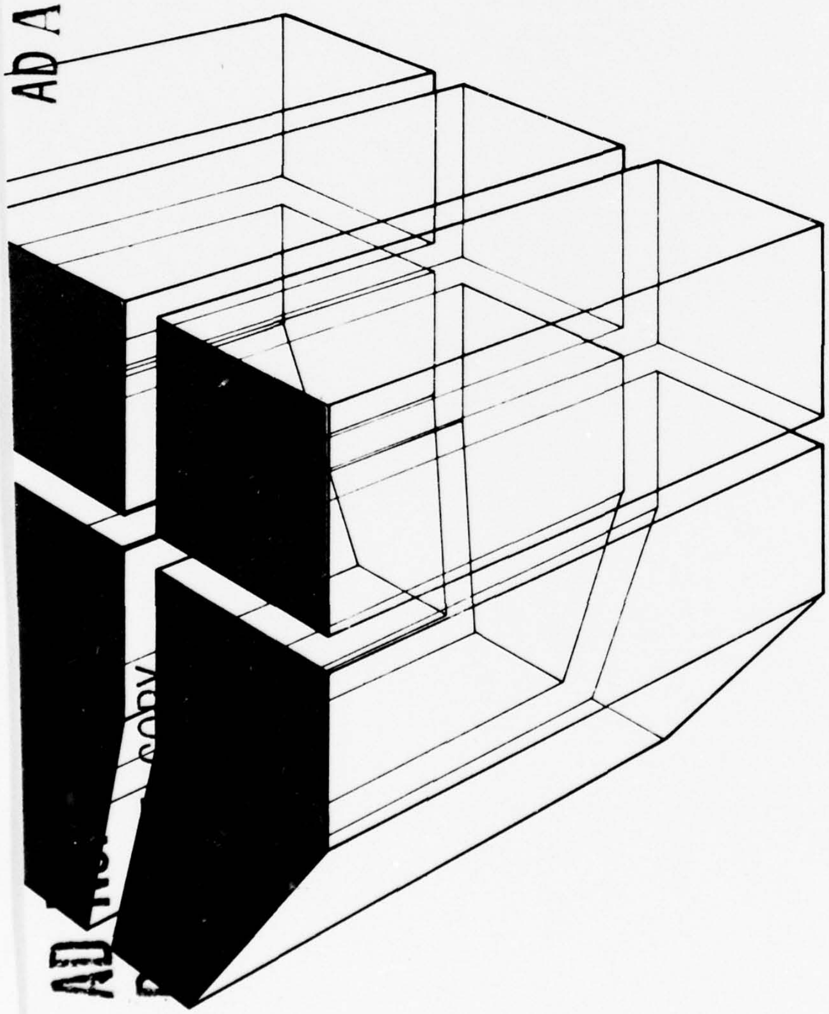
INTERIM REPORT E-115
August 1977
Central Total Energy Systems and Concepts

ANALYSIS OF CENTRAL TOTAL ENERGY SYSTEMS AT MILITARY FACILITIES



by
E. M. Honig, Jr.
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This report discusses the potential of central total energy (TE) systems for improving the efficiency and economies achieved using multiple regional TE systems. It also provides an energy and life-cycle cost analysis procedure for Corps District Engineer personnel and contracted architect-engineers to use in assessing the performance of central vs. regional TE systems. Part of the procedure involves application of computer-aided feasibility analysis to determine the number, size, and generic design of TE plants that will minimize total fuel consumption for given energy demands. The procedure also includes a method

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for determining the load for a central TE plant. A case study employing the method is presented.

The report concludes that many Army installations have enough thermal demand to justify considering centralized TE applications for a large portion of the installation. Central TE plants can be economically advantageous over regional TE plants, due primarily to economies of scale in prime movers and secondarily to increased load diversity. Central diesel plants with thermal storage were found to be most fuel-efficient, while central gas turbine plants on natural gas had the least life-cycle cost under the assumed natural gas cost structure.

It is recommended that the concept of a centralized TE system for military installations be considered when (1) a TE study is being made in conjunction with new construction, (2) several construction projects at an installation are scheduled during a 3 to 5 year time frame, and (3) an existing boiler plant is to be expanded or retrofitted.

FOREWORD

This research was performed for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under QCR 1.05.005(1), Project 4A762719AT41, "Design, Construction, and Operation and Maintenance Technology for Military Facilities"; Task 06, "Energy Systems"; Work Unit 013, "Central Total Energy Systems and Concepts." The OCE Technical Monitor was Mr. H. Maschke, DAEN-MCE-U.

The work was performed by the Energy Systems Branch (EPE), Energy and Power Division (EP), U.S. Army Construction Engineering Research Laboratory (CERL). CERL staff involved in the research were Dr. E. M. Honig, Jr. (Principal Investigator), Mr. W. H. Dolan (Mechanical Engineer), and Mr. W. Pahuchy, Jr. (Industrial Engineer). Dr. D. J. Leverenz is Chief of EPE, and Mr. R. G. Donaghy is Chief of EP.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

Total energy (TE) systems* offer the potential for using fossil fuels more efficiently than conventional energy plants. Although the total energy concept is not new, the increasing cost of fossil fuels has renewed interest in the idea. Since 1974, the Department of Defense (DoD) has required a feasibility study of total energy, selective energy,** and built-up heat pump systems for each major new construction and rehabilitation project.[1] Other government agencies, such as the Department of Housing and Urban Development (HUD), are advancing the use of total energy systems in the civilian sector.[2]

Because of the DoD directive cited, the U. S. Army Corps of Engineers has a particular responsibility for the application of TE systems in the facilities of the U. S. Army and U. S. Air Force. The Office of the Chief of Engineers (OCE) has issued instructions[3] supplementing the DoD directive and providing additional guidance for preparing feasibility studies. As part of the Corps effort, the U. S. Army Construction Engineering Research Laboratory (CERL) has conducted several studies of the methods of TE system feasibility assessment and design, as well as the standard practices of computerized prediction of energy loads in buildings and computer simulation of energy plants for buildings. These studies are described in the **Previous CERL Research** section.

*A total energy plant produces electrical energy to meet the electrical demand and recovers waste heat to meet the thermal demand.

**Selective energy plants meet the thermal demand while producing electricity; additional electric power is purchased from the local utility to meet peak electrical demand and is returned when power production exceeds demand.

[1] *Modification of DoD Construction Criteria Manual 4270.1-M* (Department of Defense, 13 September 1974).

[2] *Total Energy Systems,* HUD-381-PDR (Department of Housing and Urban Development, December 1974).

[3] *Engineering Instructions for Preparation of Feasibility Studies for Total Energy, Selective Energy, and Heat Pump Systems* (Office of the Chief of Engineers [OCE], 1 July 1975).

One aspect of TE system feasibility not studied in previous CERL research is the effect of several TE plants on the total energy production efficiency of a military installation. It is conceivable that several total energy plants might be built in a series of major construction projects at a given installation. While each plant would be sized and operated to perform optimally for the load it was to serve, the combined performance of the plants over the aggregate of loads might not be optimal, particularly if the loads were rather diverse. It is also conceivable that individual projects might not prove to be feasible, whereas a TE system for the aggregate would. These questions prompted the current study.

Objective

The objectives of this study were (1) to study the potential of centralized TE systems for improving the efficiency and economies achieved using multiple regional TE systems, and (2) to develop energy and life-cycle cost analysis procedures for Corps District Engineer personnel and contracted architect-engineers to use in assessing the performance of central vs. regional TE systems.

This report is for use by District Engineer personnel and contracted architect-engineers, as well as for the guidance of headquarters personnel.

Approach

The energy requirements, load distributions, extent of existing TE systems, central distribution systems, fuel availability, and new construction plans at the 10 largest energy-consuming Army installations were analyzed to determine if large-scale TE plants are feasible on military installations (Chapter 2).

A method was then developed for determining loads for groups of buildings to be served by central TE systems (Appendix A) and for analyzing central vs. regional TE systems (Chapter 3).

Finally, the CERL-developed Building Loads Analysis and System Thermodynamics (BLAST) program was used to evaluate candidate TE system concepts for a case study involving Fort Bragg, NC (Chapter 4). The evaluation considered integration with existing and planned energy plants, load management, fuel and water requirements, and life-cycle costs. Manpower requirements and skills were reflected by labor rates used in the BLAST program.

Scope

This report discusses application of computer-aided feasibility analysis in determining the number, size,

and generic design of TE plants that will minimize total fuel consumption for given energy demands on a military installation. It does not discuss design details of specific items of equipment.

Previous CERL Research

The first CERL total energy study[4] described the problems encountered in the feasibility assessment and design of TE systems, outlined the general framework of a computational model for solving these problems, and described the data required to validate such a model.

A second study[5] provided procedural guidance for performing feasibility analysis and preliminary design for heat-recovery systems. This study also showed that a computer simulation program consisting of an energy load profile generator, an equipment performance analysis submodel, and an economic analysis submodel was required to perform TE studies. The program would determine load profiles for heating, cooling, hot water, and electricity as functions of building parameters, building use patterns, and weather data.

CERL developed such a computer simulation model —the BLAST program[6]—to perform energy and life-cycle cost analyses of conventional, total energy, and selective energy systems. The model can be applied to groups of buildings as well as to single ones. Nearly optimal candidate energy systems can be chosen, and performance of specific components during final plant design can be estimated.

A third TE study[7] was conducted to provide a systematic procedure for applying the BLAST program in the feasibility and design phases of a TE project in order to conform to the DoD and OCE directives.

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[4] D. C. Hittle, *Total Energy and Total Utility Systems for Conservation of Resources*, Interim Report E-61/ADA023244 (U. S. Army Construction Engineering Research Laboratory [CERL], November 1974).

[5] *Procedures for Feasibility Analysis and Preliminary Design of Total Energy Systems at Military Facilities*, Technical Report E-96/ADA033756 (CERL, November 1976).

[6] D. C. Hittle, et al., *The Building Loads Analysis and System Thermodynamics Program*, Technical Report (Draft) (CERL, 1977).

[7] D. C. Hittle, *Use of the Building Loads Analysis and System Thermodynamics Program to Perform Total Energy Analysis*, Interim Report E-108 (CERL, June 1977).

2 POTENTIAL FOR CENTRAL TOTAL ENERGY SYSTEM APPLICATIONS

While the concepts of total energy are well known, it has not been clear whether application of these concepts to military facilities would be economical. The Army has no TE plants of the type used to provide electrical, heating, and cooling energy, although one post—Fort Richardson, AK—has a plant that provides both electrical and heating energy.

To roughly determine the prospect of economical application of TE concepts to military facilities, the energy requirements of the 10 most energy-consumptive Army installations were examined (Table 1). Ranking is by thermal-to-electrical demand ratio. The electrical demands (first column of Table 1) are met by purchasing electrical energy from a commercial utility company, while the thermal demands (second column) are met with various sized boiler plants on post.

For electrical production alone, an Army installation cannot economically compete with a utility company, because the utility company can use its much larger demand base and diversity to obtain large economies of scale. An installation can compete, however, if it can use the waste thermal energy generated during electrical production to offset part of its costs for heat energy. Since utility companies seldom, if ever, have customers for their waste heat, they can obtain plant efficiencies only on the order of 30 percent. Army installations, on the other hand, have large thermal demands and can thus achieve overall plant efficiencies as high as 70 percent, easily offsetting the economy-of-scale advantages of utility companies. To achieve this, however, an installation must have sufficient thermal demand occurring when the waste energy from electrical production is available.

TE plants generally have an overall efficiency of approximately two-thirds, with one-third of the input energy typically going to electrical production, one-third to recoverable thermal energy, and one-third as lost waste heat. Thus, on an annual basis, the ratio of usable waste thermal demand to electrical demand is 1:1. However, because the electrical and thermal demand profiles are usually not equal, a greater total thermal demand is generally required before the post thermal demand and the waste thermal energy available coincide (even with energy storage).

Table 1
Summary of Installation Energy Requirements*

Installation	Annual Electrical Demand GW-h	Annual Electrical Demand GBtu	Annual Thermal Demand GBtu (TJ)	Ratio of Thermal to Electrical Demand	Peak Electrical Demand MW_e
Holston AAP, TN	91	310	5062 (5340)	16.3	–
Redford AAP, VA	126	429	3883 (4097)	9.1	–
Fort Knox, KY	127	435	2391 (2523)	5.5	30.9
Aberdeen Proving Ground, MD	123	419	1921 (2027)	4.6	–
Fort Lewis, WA	141	480	2131 (2248)	4.4	36.4
Fort Benning, GA	151	516	2047 (2160)	4.0	37.6
Fort Bragg, NC	222	752	2681 (2828)	3.6	48.6
Fort Hood, TX	192	655	1820 (1920)	2.8	42.6
Redstone Arsenal, AL	263	899	1872 (1975)	2.1	–
Fort Meade, MD	218	744	1488 (1570)	2.0	43.4

*Data of first two columns are FY75 figures taken from *Facilities Engineering Annual Summary of Operations* (OCE, 1975). Data of fourth column are FY74 figures taken from *Characterization of Energy Usage on Military Installations*, Table 12, by H. D. Hollis and A. V. Nida (USA FESA, 1974).

Column 3 in Table 1 shows the ratio of thermal to electrical demand for the Army's 10 largest energy users. In all cases, the ratio is 2 or greater; for six cases, it is 4 or greater. This indicates that there is a good chance that a TE system would be efficient for most and possibly all of these posts. Large amounts of the electrical demand at posts with lower thermal/electrical ratios are for summer cooling; part of this demand could be converted to absorption cooling to help match the electrical and thermal profiles when necessary.

One of the problems that must be considered in central TE system studies is the distribution of waste thermal energy to users. If the load points are small and widely distributed, the distribution system's cost and thermal losses would make the TE system impracticable, even with a high thermal load. Table 2 shows the data from Table 1 with thermal demands from heating units smaller than 0.75 MBtu-h (0.79 GJ-h) (i.e., family housing type units) eliminated. All but two of the posts still have thermal to electrical demand ratios of approximately 2 or greater. When only the thermal demand for heating plants exceeding 3.5 MBtu-h (3.7 GJ-h) is included (Table 3), five of the posts still have thermal to electrical demand ratios of nearly 2 or greater. These larger plants typically already have thermal distribution systems.

The data in Tables 1, 2, and 3 clearly indicate that Army installations have sufficient thermal demand to justify considering centralized total energy applications for a large portion of each post. In addition, enough large heating plants exist at most installations so that implementing a central total energy system would require only minor additions to the thermal distribution systems. Fort Bragg, which has four central heating plants with existing distribution systems, is a good example of this. The thermal demand from these four heating plants (Table 4) exceeds the post electrical demand during the heating season. By converting some summer cooling demand to thermal demand with absorption chillers, it should be possible to get an excellent thermal/electrical match over the whole year. This indicates that a central TE system used in place of these plants could supply most of the post's electrical demand with only a minor requirement for additional thermal distribution systems.

Table 2
Summary of Installation Energy Requirements
(Heating Units Larger than 0.75 MBtu [0.79 GJ] Only*)

Installation	Annual Electrical Demand GW-h	Annual Electrical Demand GBtu	Annual Thermal Demand GBtu (TJ)	Ratio of Thermal to Electrical Demand	Peak Electrical Demand MW_e
Holston AAP, TN	91	310	5058 (5336)	16.3	–
Radford AAP, VA	126	429	3883 (4097)	9.1	–
Aberdeen Proving Ground, MD	123	419	1514 (1597)	3.6	–
Fort Knox, KY	127	435	1043 (1100)	2.4	30.9
Fort Bragg, NC	222	752	1652 (1743)	2.2	48.6
Fort Benning, GA	151	516	1024 (1080)	2.0	37.6
Fort Lewis, WA	141	480	959 (1012)	2.0	36.4
Redstone Arsenal, AL	263	899	1739 (1835)	1.9	–
Fort Meade, MD	218	744	749 (790)	1.0	43.4
Fort Hood, TX	192	655	422 (445)	.64	42.6

*Data of first two columns are FY75 figures taken from *Facilities Engineering Annual Summary of Operations* (OCE, 1975). Data of fourth column are FY74 figures taken from *Characterization of Energy Usage on Military Installations*, Table 12, by H. D. Hollis and A. V. Nida (USA FESA, 1974).

Table 3
Summary of Installation Energy Requirements
(Heating Units Larger than 3.5 MBtu (3.7 GJ) Only*)

Installation	Annual Electrical Demand GW-h	Annual Electrical Demand GBtu	Annual Thermal Demand GBtu (TJ)	Ratio of Thermal to Electrical Demand	Peak Electrical Demand MW_e
Holston AAP, TN	91	310	5050 (5328)	16.3	–
Radford AAP, VA	126	429	3883 (4097)	9.1	–
Aberdeen Proving Ground, MD	123	419	1181 (1246)	2.8	–
Fort Benning, GA	151	516	985 (1039)	1.9	37.6
Redstone Arsenal, AL	263	899	1715 (1808)	1.9	–
Fort Bragg, NC	222	752	1247 (1316)	1.65	48.6
Fort Lewis, WA	141	480	754 (795)	1.6	36.4
Fort Knox, KY	127	435	443 (467)	1.0	30.9
Fort Meade, MD	218	744	499 (526)	.67	43.4
Fort Hood, TX	192	655	274 (289)	.42	42.6

*Data of first two columns are FY75 figures taken from *Facilities Engineering Annual Summary of Operations* (OCE, 1975). Data of fourth column are FY74 figures taken from *Characterization of Energy Usage on Military Installations*, Table 12, by H. D. Hollis and A. V. Nida (USA FESA, 1974).

Table 4
Fort Bragg Monthly Thermal and Electrical Demands
Thermal Loads, GBtu (TJ)

Month	Hospital Heating Plant		82nd Airborne Heating Plant		CMA Heating Plant		Laundry Heating Plant		Total		Post Electrical Demand GBtu (TJ)	
Jan	25.088	(26.468)	79.479	(83.850)	19.152	(20.205)	4.636	(4.891)	128.3	(135.4)	57.667	(60.839)
Feb	21.063	(22.221)	72.475	(76.461)	17.455	(18.415)	4.546	(4.796)	115.5	(121.9)	59.102	(62.353)
Mar	23.149	(24.422)	67.545	(71.260)	17.927	(18.913)	4.840	(5.106)	113.5	(119.7)	53.902	(56.867)
Apr	19.018	(20.064)	36.667	(38.684)	12.354	(13.033)	3.936	(4.152)	72.0	(76.0)	52.263	(55.137)
May	11.451	(12.081)	26.488	(27.945)	9.987	(10.536)	3.647	(3.848)	51.6	(54.4)	56.158	(59.247)
Jun	9.563	(10.089)	36.051	(38.034)	7.630	(8.050)	4.403	(4.645)	57.6	(60.8)	74.759	(78.871)
Jul	11.072	(11.681)	37.073	(39.112)	7.845	(8.276)	4.170	(4.399)	60.1	(63.4)	75.735	(79.900)
Aug	9.963	(10.511)	42.198	(44.519)	7.087	(7.477)	2.643	(2.788)	61.9	(65.3)	74.624	(78.728)
Sep	11.554	(12.189)	35.170	(37.104)	6.805	(7.179)	3.017	(3.183)	56.5	(59.6)	79.919	(84.315)
Oct	11.594	(12.232)	22.110	(23.326)	6.922	(7.303)	4.354	(4.593)	45.0	(47.5)	57.503	(60.666)
Nov	12.021	(12.682)	34.597	(36.500)	14.317	(15.104)	5.358	(5.653)	66.3	(69.9)	53.033	(55.950)
Dec	18.529	(19.548)	60.729	(64.069)	23.686	(24.989)	4.901	(5.171)	107.8	(113.7)	57.445	(60.604)
Total	184.065	(194.189)	550.582	(580.864)	151.167	(159.481)	50.451	(53.226)	936.1	(987.6)	752.110	(793.466)

The analysis of the Army's 10 largest energy users indicates that the concept of centralized TE systems should be considered, particularly in the following circumstances:

1. When a TE study is being made in conjunction with a new construction project in accordance with the DoD directive. The study should include expansion of the system to include surrounding thermal loads and other electrical loads as described in CERL Technical Report E-96.[8]

2. When several new construction projects are scheduled for one installation during a relatively short time period (3 to 5 years). The study should include consideration of one TE plant which could be expanded to meet the needs of all the new construction plus the possibility of meeting the loads for existing construction in the area between or adjacent to the construction site.

3. When an existing central heating plant is to be expanded or have a major boiler retrofit. Consideration should be given to replacing the plant with a central TE plant.

Because Army installations have complete control over the loads distribution systems, there is an excellent opportunity to optimize the loads on an installation to obtain maximum efficiency from a TE plant without having to resort to selective energy systems. For this reason, methods for expanding TE studies to include centralized TE concepts were examined and are discussed in the remainder of this report.

[8] *Procedures for Feasibility Analysis and Preliminary Design of Total Energy Systems at Military Facilities*, Technical Report E-96/ADA033756 (CERL, November 1976).

3 METHODOLOGY FOR EVALUATING CENTRAL TOTAL ENERGY PLANTS

General

TE studies for military installations have generally been applied to single construction projects such as barracks complexes, hospitals, and large multistory buildings. A detailed method for feasibility and economic analysis and design of these plants was developed in the report *Use of the Building Loads and System Thermodynamics Program to Perform Total Energy Systems Analysis.*[9] This method, which is in accord with OCE life cycle costing procedures,[10] can also be used with some slight modifications to study central TE plants to account for the differences between central and regional total energy plants. The major differences which must be considered are:

1. Larger plants can be used for centralized TE systems, meaning greater economy of scale in equipment and buildings and reductions in operating personnel can be achieved. These plants necessitate that the simulation program accommodate a wider variety of equipment sizes and types (such as steam turbines) than is needed for single construction projects.

2. Central total energy systems will cover larger geographical areas. Thus, the economic, thermal energy storage, and energy loss aspects of the thermal distribution system must be considered in the study. Since the same electrical distribution system is generally required in either case, it can be ignored for comparison studies.

The methodology described in this chapter for studying central TE plants must address these features in addition to those considered in the standard TE study.

Performance Analysis of Large Total Energy Plants

The methodology for performance and economic analyses of total energy plants for a military installation described by Hittle[11] applies regardless of size, provided the hourly loads on the plant are known. (The **Load Determination** section describes how these loads can be found.) However, the scope of the Central Energy Plant Simulator (CEPS) portion of CERL's BLAST program was expanded to accommodate analysis of the larger TE plants which must be considered when central TE plants are addressed. This primarily involved adding algorithms to handle larger components and including algorithms to analyze the performance and economics of gas-, oil-, and coal-fired steam turbine plants. For the data in Table 1, the largest peak plant capacity required for these Army installations is about 50 MW_e. This size system can be accommodated by the BLAST program.

Load Determination

Determination of loads for a central TE study is somewhat more complex than for standard TE studies, since the distribution system and many more buildings must be considered in the former case. The following sections describe the two methods for obtaining the required loads: using metered data and using computer simulation programs.

Obtaining Loads From Available Data

Using metered data will provide the most accurate loads, but there are two major drawbacks: (1) existing energy consumption data for Army installations are generally available only for large power plants or for the whole installation, and (2) these data are seldom on an hourly basis as is commonly required for TE plant studies. Metering installations to obtain this data is both costly and extremely time-consuming, and thus is almost never practicable. Loads can usually be synthesized from existing consumption data, even when limited, if the proper engineering approximations are made. In general, this method relies on the following steps:

1. Dividing the post into regional load centers (such as barracks complexes, family housing areas, hospitals, administrative areas, or areas presently served by centralized heating systems). The components of a given load center should have similar building occupancy and use patterns, construction type, and energy requirements; i.e., each load center is homogeneous in its components.

2. Obtaining a representative energy consumption profile for one typical component of each load center.

3. Scaling the energy consumption profile to account for weather conditions and the number of components in the load center. Energy consumption

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[9] D. C. Hittle, *Use of the Building Loads Analysis and System Thermodynamics Program to Perform Total Energy Analysis*, Interim Report E-108 (CERL, June 1977).

[10] *OCE Life Cycle Costing Instructions* (Department of the Army, May 1971).

[11] D. C. Hittle, *Use of the Building Loads Analysis and System Thermodynamics Program to Perform Total Energy Analysis*, Interim Report E-108 (CERL, June 1977).

profiles can be scaled on the basis of square feet of building area, energy use indices,[12] and/or metered data.

Centralized TE studies often consider existing central plants as load centers, rather than using steps 2 and 3 above. Hence, a reasonable amount of metered data may be available from which to construct a consumption profile. If sufficient data are not available, energy consumption profiles can be obtained from computer simulation (as discussed below) or from measured data for buildings similar to those in the load center. Such measured data should be available from CERL's fixed facility energy consumption investigation in FY78. Information for accessing these data is currently in draft form.[13]

When using the metered data method for load determination, losses are accounted for on a per foot of distribution system basis. Energy storage in the distribution system is not accounted for. Appendix A describes the method in greater detail.

Load Determination by Computer Simulation

Energy consumption profiles for building types can be obtained by using the BLAST program in the three-step procedure discussed above. The load center profiles can be obtained by scaling the building type profiles by the respective number of building types considered and summing the results.

Summary

The method for central plant analysis is thus a five-step procedure:

1. Divide the installation or a portion of the installation into load centers, with the components of a given load center having similar energy consumption patterns.

2. Determine the load for each load center by load synthesis (as described in Appendix A) or by using the BLAST program.

3. Select several adjacent load centers as loads for a TE plant.

4. Using the CEPS portion of the BLAST program and the procedure described by Hittle,[14] optimize the TE plant, based on life-cycle cost, which will meet the total loads obtained in step 3 of the *Obtaining Loads From Available Data* section.

5. Repeat step 4 for various combinations of load centers to determine whether a centralized TE plant, two or more regional TE plants, or a selective TE plant provides the system having the lowest life-cycle cost.

Based on the results of step 5, partially redefining the load centers or their combinations may be necessary to get a better thermal and electrical load match and to provide increased load diversity. This adjustment must be based on engineering judgment.

4 CASE STUDY FOR FORT BRAGG, NC

This chapter presents a central TE case study of Fort Bragg, NC, using CY75 data. The case study was conducted to demonstrate the method explained in Chapter 3 and to highlight some of the features differentiating central and regional TE systems. Fort Bragg was selected for several reasons: (1) it is a large consumer of energy, (2) records of its energy consumption and management in CY75 were readily available, and (3) the analysis discussed in Chapter 2 indicated that a central TE system used in place of the four existing boiler plants could supply most of the post's electrical demand with only a minor requirement for additional thermal distribution systems.

Electrical Load

The post receives electrical power from two commercial sources; one meter is provided for each source as power enters the military property. Information furnished by the post Facility Engineer for one source consisted of electrical demand data at 15-minute intervals for 365 days of 1975; monthly totals were furnished for the other source.

The procedure given in the *Interval Demand Recorders With Integrating Demand Meters* section of Appendix A was used to synthesize an hourly electrical load profile for the post. Hourly and daily scaling

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[12] T. Alereza, B. K. Hinkle, D. C. Hittle, J. E. Piper, and L. M. Windingland, *Energy Utilization Index Method for Predicting Building Energy Use*, Interim Report E-105 (CERL, May 1977).

[13] L. M. Windingland and B. J. Sliwinski, *Fixed Facilities Energy Consumption Investigation Data Users Manual*, Interim Report (Draft) (CERL, 1977).

[14] D. C. Hittle, *Use of the Building Loads Analysis and System Thermodynamics Program to Perform Total Energy Analysis*, Interim Report E-108 (CERL, June 1977).

factors were computed as directed in the procedure. Thus, an hourly post electrical load was determined by dividing the monthly electrical consumption (taken from both electric utilities) by the number of days in the month and multiplying by the daily and hourly scaling factors appropriate for the season, month, and type of day (weekday or weekend). Figure 1 shows the resulting electrical load profile.

Thermal Load

The post Facility Engineer provided hourly boiler logs for the four boiler plants on post—the Hospital, the 82nd Airborne, the CMA, and the post laundry—for 1 week each of January, April, and July 1975.

Step 2 of the procedure given in the **Thermal Load** section of Appendix A was used to synthesize an hourly thermal load profile for each of the four thermal distribution systems. Each distribution system was then modeled as a thermal load center. Tables 5 through 7 present formulas for computing the thermal loads for specific plants and seasons.* Figures 1 through 5 show the resulting thermal load profiles for each plant and the post.

These electrical and thermal loads, along with a weather tape (for air temperature and humidity) for the Fort Bragg region, were input to the CEPS program.

Cost and Life-Cycle Parameters

The values assigned to these parameters were the default values provided by the BLAST program (Table 8).

Energy Plant Simulation

Each of the four existing boiler plants was modeled over CY75 as a conventional energy plant with new equipment that met the existing thermal load. Next, each of the four plants was simulated as a TE plant in which various prime movers were investigated. Finally, a single TE plant meeting the postwide electrical and thermal demands was simulated.

Thermal and electrical loads were assigned to the models of the plants on the basis of the thermal load data from each plant. First, each of the four regional plant models (or simulations) was assigned the thermal load profile derived from data (Figs. 2-5) recorded for that plant for CY75. This was true for both conventional and TE plant simulations. The thermal load of the single TE plant model was the sum of the thermal loads of the regional plant models plus an additional fraction accounting for distribution loss.

Electrical loads were assigned using the assumption that a diesel generator set produces equal amounts of electrical and thermal energy. Thus, the laundry plant was assigned an electrical load equal to the laundry thermal load. The remaining electrical load of the post was assigned so that the ratio of the electrical to thermal load at each of the three remaining plants was equal to the ratio of the total remaining electrical load to the total remaining thermal load. This ratio can also be expressed as the ratio of the total electric less laundry electric load to the total thermal less laundry thermal load. The value of this ratio changed hourly throughout the modeling.

The number of prime movers was assumed to be two (plus one in reserve). This would permit the maximum economy of scale. In practice, more units might offer greater reliability but not necessarily greater fuel efficiency. The units were sized according to the following rules (not official OCE criteria):

1. Standard unit size (three prime movers) = (half maximum demand) × (.6)

2. If standard unit size < (minimum demand)/.4
   a. Small unit size (1) = minimum demand/.4
   b. Large unit size (2) = (1.2) × (maximum demand − small unit size).

Gas turbines were modeled as being fueled by natural gas in one case and oil in another.

Prime movers as large as 13.2 MW in regional TE plants and 24.9 MW in central TE plants were selected by these rules. Inspection of *Diesel and Gas Turbine Worldwide Catalog*[15] shows that several foreign manufacturers make diesel generator sets in these sizes, but American manufacturers presently do not. Gas turbine generators in these sizes can be purchased from U.S. firms, however. A "buy American" problem for diesel generators could be solved by using four to six 8-MW units, which are made by several U.S. firms. The results of the following study would not vary significantly from the results obtained with four or six 8-MW units.

Boilers in conventional plants were sized to be the same as boilers actually in the existing plants. Boilers in TE plants were sized using the following rules (not official OCE criteria):

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[15] *Diesel and Gas Turbine Worldwide Catalog*, Vol 41 (1976).

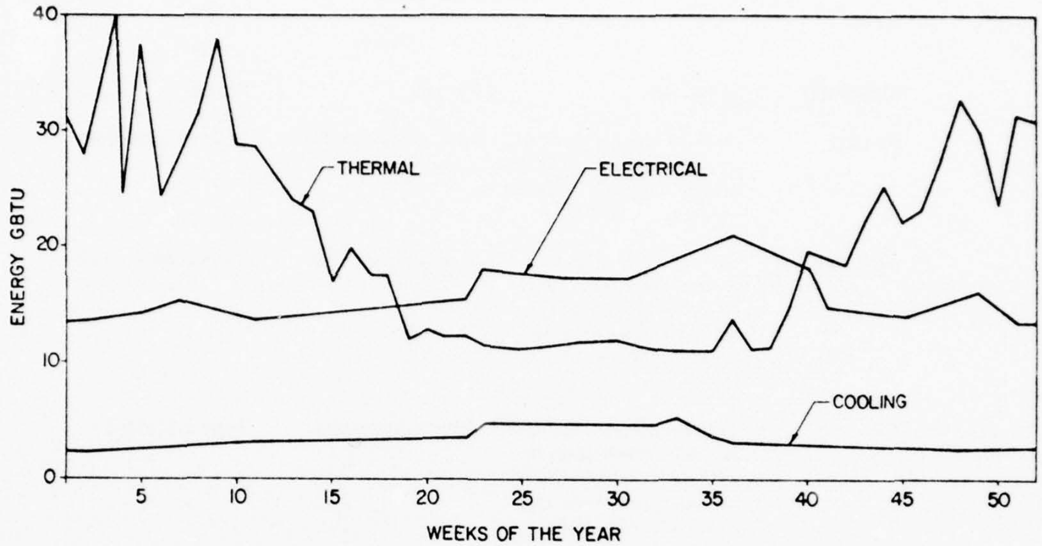

Figure 1. Weekly postwide energy demands for CY75.
SI conversion factor: 1 Btu = 1.055 kJ.

Table 5
Thermal Demand for Cooling

Boiler Plant	**Season** Spring/Fall	Summer	Winter
Hospital	None (compression chiller)	None (compression chiller)	None (compression chiller)
82nd Airborne	Constant	f_s^{82} (T) × (summer hourly scale factors) – (steam users summer load)*	Constant
CMA	None	Constant, 1000 to 2400 hour; decreasing linearly to 0.6 of constant, 2400 to 0600; increasing linearly to constant, 0600 to 1000 hours	None
Laundry	None	None	None

*The symbol $f_{()}^{()}$ (T) is defined in Appendix A.

Table 6
Steam Users Load

	Season		
Boiler Plant	**Spring/Fall**	**Summer**	**Winter**
Hospital	(Average summer thermal load on successive warm days over 76°F [24°C]) × (summer hourly scale factors)	Same as Spring/Fall	Same as Spring/fall
82nd Airborne	(Average thermal load on successive warm days over 76°F [24°C]) × (spring/fall hourly scale factors) – (spring/fall/winter cooling load)	Same as Spring/Fall	Same as Spring/Fall
CMA	(Average thermal load on successive warm days over 76°F [24°C]) × (spring/fall hourly scale factors) – (seasonal cooling load)	Same as Spring/Fall	Same as Spring/Fall
Laundry	(Monthly average daily steam consumption) × (spring/fall hourly scale factors)	(Monthly average daily steam consumption) × (summer hourly scale factors)	(Monthly average daily steam consumption) × (winter hourly scale factors)

Table 7
Heating Load

	Season		
Boiler Plant	**Spring/Fall**	**Summer**	**Winter**
Hospital	$f^{H}_{sf}(T)$ × (spring/fall hourly scale factors) – (hourly steam users load)	None	$f^{H}_{w}(T)$ × (winter hourly scale factors) – (hourly steam users load)
82nd Airborne	$f^{82}_{sf}(T)$ × (spring/fall hourly scale factors) – (steam users load) – (spring/fall/winter cooling load)	None	$f^{82}_{w}(T)$ × (winter hourly scale factors) – (steam users load) – (spring/fall/winter cooling load)
CMA	$f^{CMA}_{sf}(T)$ × (spring/fall hourly scale factors) – (steam users load)	None	$f^{CMA}_{w}(T)$ × (winter hourly scale factors) – (steam users load)
Laundry	None	None	None

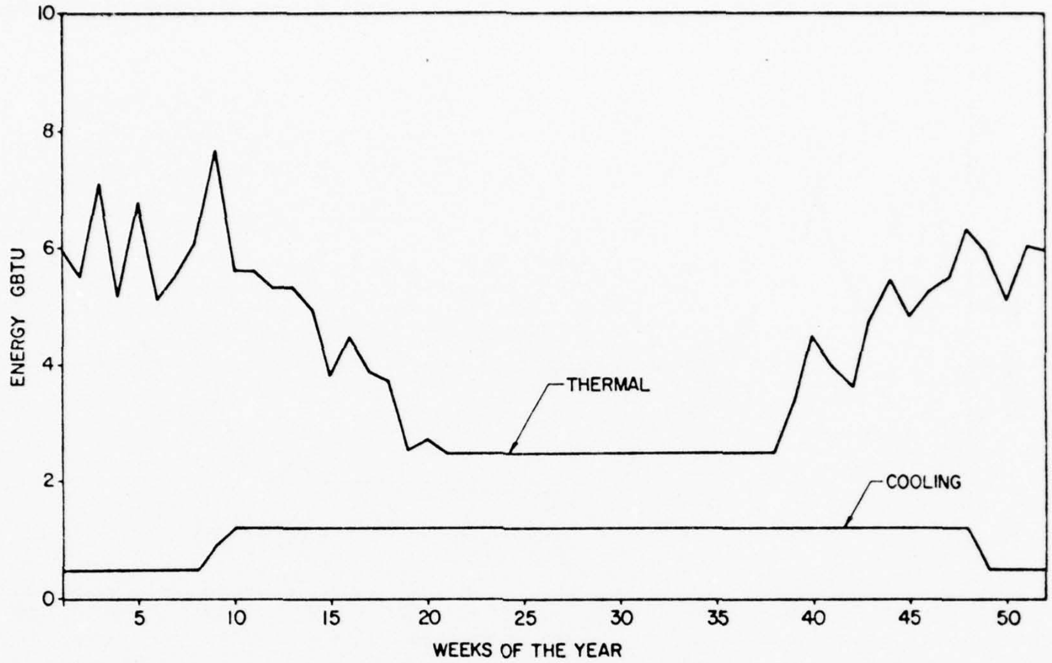

Figure 2. Hospital boiler plant weekly energy demands for CY75.
SI conversion factor: 1 Btu = 1.055 kJ.

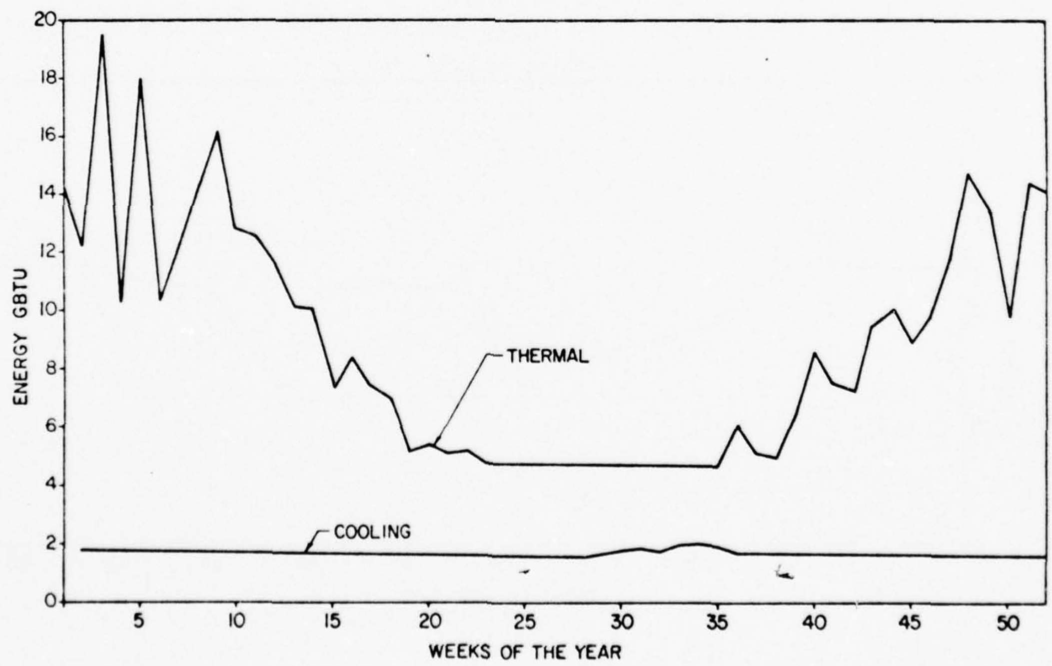

Figure 3. 82nd Airborne boiler plant weekly energy demands for CY75.
SI conversion factor: 1 Btu = 1.055 kJ.

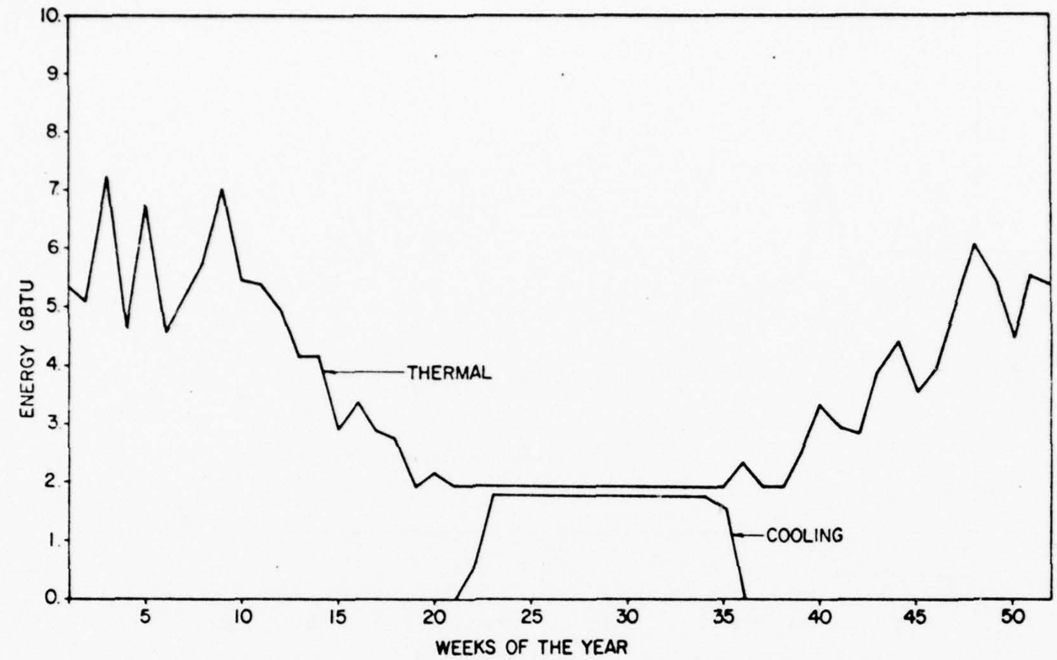

Figure 4. CMA boiler plant weekly energy demands for CY75.
SI conversion factor: 1 Btu = 1.055 kJ.

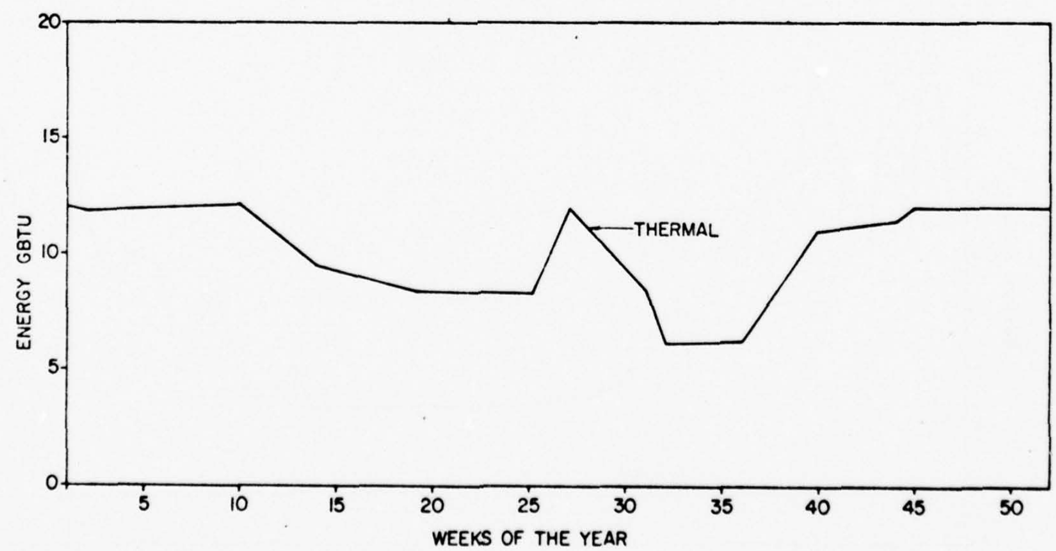

Figure 5. Laundry boiler plant weekly energy demands for CY75.
SI conversion factor: 1 Btu = 1.055 kJ.

Table 8
Life-Cycle Parameters

Interest Rate		6.5%
Inflation Rates		
Labor		4.0%
Material		4.0%
Energy		4.0%
Project Life		25 years
Labor Cost		\$20/hr
Energy Cost		
Gas	\$ .15/therm (100,000 Btu) (\$1.40/GJ) Cost Escalation Factor 57.7	
Oil	\$ .40/gal (130,000 Btu) (\$105.68/m³) Cost Escalation Factor 42.4	
Electricity	\$ .008/kW-h after 250 kW-h (\$0.002/MJ after 900 MJ) \$0.12/kW-h first 250 kW-h cost (0.003/MJ first 900 MJ) Demand \$1.0/kW Cost Escalation Factor 61.9	

1. Capacity of each boiler does not exceed 100 MBtuh (29.3 MW)

2. In each plant, one boiler is twice the minimum thermal load (i.e., boiler always operates at no less than half of full load)

3. Number of remaining boilers = I(z + 1)

$$\text{where } z = \frac{\text{max thermal load} - 2 \times \text{min thermal load}}{100 \text{ MBtuh}},$$

a dimensionless number

I(z + 1) = largest integer in z + 1, a function

$$\text{4. Size of remaining boilers} = \frac{z \times 100 \text{ MBtuh}}{I(z + 1)}$$

5. Sum of boiler capacities is not less than the thermal demand in absence of electrical generation; this was usually met by adding one more boiler of the size given in rule 4.

Chillers were sized to meet demand in convenient industrial units, such as 4 MBtuh (1.2 MW) (333 ton cooling). Cooling towers were similarly sized in quantities to handle diesels and chillers assigned. In some cases, similarly sized thermal storage tanks were used for peak shaving, or load leveling.

The hospital was simulated in four equipment configurations (Table 9). Table 10 presents the energy consumption and life-cycle cost results, with detailed summaries appearing in Appendices B and C. A boiler plant with existing equipment would require the purchase of 206 GBtu (217 TJ) of electricity with an \$88 million life-cycle cost. The diesel plant with thermal storage is more efficient—70 percent—and less expensive than without storage. Using thermal storage with the diesels cuts the operating time of the cooling tower to less than one-half the time without storage. Use of the diesels and chillers is also decreased somewhat. The gas turbine plant is less expensive than the diesel plants if natural gas is used, but not if fuel oil is used.

The 82nd Airborne energy plant was also modeled in the four equipment configurations (Table 11). Energy consumption and life-cycle cost results are presented in Table 10. Appendices B and C present detailed summaries. The model of the existing boiler plant ran at 42 percent efficiency and required the purchase of 407 GBtu (429 TJ) of electricity. Diesel with thermal storage is more efficient (69 percent) and

Table 9
Hospital Energy Plant Equipment Utilization

Equipment	Number	Size MBtuh (MW)	Average Operating Ratio	Maximum Load MBtuh (MW)	Maximum Load Date mo/da/hr	Operating Hours
		Configuration H-1 (Existing Boiler Plant)				
Boiler	2*	37.8 (11.1)	0.64	58.3 (17.1)	2/ 3/13	11,704
Absorption Chiller**	1	3.6 (1.1)	0.94	3.6 (1.1)	11/30/24	9,760
Cooling Tower	1	12.0 (3.5)	0.69	8.9 (2.6)	11/30/24	9,760
		Configuration H-2 (Diesel)				
Diesel	2*	29 (8.5)	0.56	57.8 (16.9)	9/11/17	13,249
Boiler	3	20 (5.9)	0.54	33.4 (9.8)	1/31/ 7	5,859
Absorption Chiller**	1	8 (2.3)	0.73	7.7 (2.3)	11/30/20	8,269
Compression Chiller	1	4 (1.2)	0.60	4.0 (1.2)	11/30/24	2,075
Cooling Tower	7	12 (3.5)	0.51	72.2 (21.2)	9/11/18	31,901
		Configuration H-3 (Diesel with Thermal Storage)				
Diesel	2*	29 (8.5)	0.55	57.7 (16.9)	9/11/17	13,174
Boiler	3	20 (5.9)	0.53	33.2 (9.7)	1/31/ 7	5,880
Absorption Chiller**	1	8 (2.3)	0.49	8.0 (2.3)	9/28/10	7,690
Compression Chiller	1	4 (1.2)	0.59	4.0 (1.2)	11/30/24	1,980
Cooling Tower	3	24 (7.0)	0.41	68.9 (20.2)	9/19/17	14,333
Hot Water Tank	1	12 (3.5)	0.07	12.0 (3.5)	4/10/ 1	1,212
Cold Water Tank	1	8 (2.3)	0.11	7.7 (2.3)	10/21/14	8,365
		Configuration H-4 (Gas Turbine)				
Gas Turbine	2*	29 (8.5)	0.55	57.0 (16.7)	9/11/17	13,212
Boiler	3	20 (5.9)	0.53	27.7 (8.1)	1/31/ 7	3,185
Absorption Chiller**	1	8 (2.3)	0.75	7.7 (2.3)	11/30/23	8,635
Compression Chiller	1	4 (1.2)	0.45	4.0 (1.2)	11/30/10	742
Cooling Tower	3	12 (3.5)	0.88	36.0 (10.6)	12/31/20	25,372

*Plus one reserve unit.

**Single stage.

less costly than without storage (66 percent). Gas turbines have a somewhat lower life-cycle cost for natural gas operation than diesel; however, when oil is used in the turbines, costs are greater than for diesel.

The CMA energy plant was modeled in the four configurations reported in Table 12. Table 10 presents the energy consumption and life-cycle costs; detailed summaries are presented in Appendices B and C. A boiler plant was modeled in place of the high temperature hot water system actually used in the CMA plant. The results were similar to those for the 82nd Airborne plant; diesel with thermal storage is more efficient and less costly than without storage. When operating on natural gas, gas turbines have a somewhat lower life-cycle cost than diesels; this is not true when the turbines use fuel oil.

The laundry plant was likewise modeled in four configurations (Table 13). Energy consumption and life-cycle costs appear in Table 10, while detailed summaries are presented in Appendices B and C. Thermal storage was used for only 2 hours in configuration L-3, so that costs were increased slightly without any operating benefits. The gas turbine plant using natural gas operated almost as efficiently as the diesel plants and at significantly lower cost. When placed on oil, this plant was only slightly more expensive than the diesel

Table 10
Energy Consumption and Life-Cycle Cost

Configuration	Average Annual Efficiency %	Annual Energy Consumption, GBtu (TJ): Oil: Diesel	Oil: Turbine	Natural Gas: Turbine	Natural Gas: Boiler	Electricity**	Total	Equipment Cost in 25 Years, M$	Life-Cycle Cost in 25 years, M$
			Hospital Energy Plant						
H-1	43	—	—	—	388 (409)	206 (217)	594 (627)	5.98	88.48**
H-2	66	674 (711)	—	—	89 (94)		763 (805)	23.10	118.73
H-3	70	669 (706)	—	—	87 (92)		756 (798)	23.08	116.85
H-4NG*	51	—	—	947 (999)	48 (51)		995 (1050)	23.88	109.96
H-4O*	51	—	947 (999)	—	48 (51)		995 (1050)	23.88	151.55
			82nd Airborne Energy Plant						
A-1	42	—	—	—	853 (900)	407 (429)	1260 (1329)	13.06	179.50**
A-2	66	1293 (1364)	—	—	220 (232)		1513 (1596)	31.94	219.69
A-3	69	1282 (1353)	—	—	213 (225)		1495 (1577)	31.31	216.98
A-4NG	52	—	—	1777 (1875)	113 (119)		1890 (1994)	35.33	198.89
A-4O	52	—	1777 (1875)	—	113 (119)		1890 (1994)	35.33	276.91
			CMA Energy Plant						
C-1	44	—	—	—	326 (344)	167 (176)	493 (520)	5.79	73.03**
C-2	65	544 (574)	—	—	62 (65)		606 (639)	19.43	95.76
C-3	66	543 (573)	—	—	62 (65)		606 (639)	19.46	95.60
C-4NG	48	—	—	783 (826)	24 (25)		807 (851)	21.69	91.59
C-4O	48	—	783 (826)	—	24 (25)		807 (851)	21.69	125.99
			Laundry Energy Plant						
L-1	40	—	—	—	87 (92)	52 (55)	139 (147)	2.76	27.95**
L-2	49	184 (194)	—	—	36 (38)		220 (232)	13.01	40.12
L-3	49	184 (194)	—	—	36 (38)		220 (232)	13.03	40.13
L-4NG	47	—	—	227 (239)	—		227 (239)	12.41	32.08
L-4O	47	—	227 (239)	—	—		227 (239)	12.41	42.07
			Central Total Energy Plant						
P-1	39	—	—	—	2338 (2467)	832 (878)	3170 (3344)	12.08	396.79**
P-2	65	2648 (2794)	—	—	378 (399)		3028 (3192)	45.95	424.11
P-3	69	2626 (2770)	—	—	372 (392)		2998 (3163)	45.22	419.99
P-4NG	53	—	—	3503 (3696)	188 (198)		3691 (3894)	50.12	369.62
P-4O	53	—	3503 (3696)	—	188 (198)		3691 (3894)	50.12	523.46
P-5	66	2657 (2803)	—	—	565 (596)		3222 (3399)	46.93	442.44

*NG = natural gas
O = fuel oil

**Does not represent fuel energy wasted by utility to make electricity.

plants. The basic problem in these laundry plant models is good use of low-temperature heat.

Postwide load operation was simulated in five configurations (Table 14). Table 10 also gives these energy consumption and life-cycle cost results, with details in Appendices B and C. The diesel plant with thermal storage was the most efficient of any plant and cost less than a diesel plant without storage. The gas turbine plant running on natural gas was the least expensive; when running on oil, it was the most expensive. Configuration P-5 illustrates the effect of thermal losses due to thermal distribution. The configuration consisted of a central heating and electrical plant, with steam and electricity being sent to the sites of the existing steam plants for the production of cooling energy. The thermal load was increased by 15 percent to simulate distribution losses. The large life-cycle cost reflects this assumed loss. Transmission losses are not explicit in any of the other models.

Table 11
82nd Airborne Energy Plant Equipment Utilization

Equipment	Number	Size MBtuh (MW)	Average Operating Ratio	Maximum Load MBtuh (MW)	Maximum Load Date mo/da/hr	Operating Hours
		Configuration A-1 (Existing Boiler Plant)				
Boiler	3	95 (27.8)	0.61	173.0 (50.7)	1/31/ 7	10,220
Absorption Chiller†	2	11.7 (3.4)	0.0	0.0 (0.0)	–	
Absorption Chiller††	1	9.8 (2.9)	0.49	15.1 (4.4)	8/14/11	8,768
		12 (3.5)				8,768
Cooling Tower	4	12 (3.5)	0.51	28.2 (8.3)	8/14/11	27,668
		Configuration A-2 (Diesel)				
Diesel	2*	45 (13.2)	0.58	89.4 (26.2)	9/ 9/15	15,808
Boiler	3	50 (14.7)	0.50	139.7 (40.9)	1/31/ 7	2,348
	1**	30 (8.8)	0.50	139.7 (40.9)	1/31/ 7	6,435
Absorption Chiller†	2	8 (2.3)	0.67	15.1 (4.4)	8/14/11	17,520
Cooling Tower	3	36 (10.6)	0.48	98.1 (28.8)	9/ 4/18	19,949
		Configuration A-3 (Diesel With Thermal Storage)				
Diesel	2*	45 (13.2)	0.58	89.3 (26.2)	9/ 9/15	15,736
Boiler	1**	30 (8.8)	0.49	139.7 (40.9)	1/31/ 7	6,478
	3	50 (14.7)	0.49	139.7 (40.9)	1/31/ 7	2,229
Absorption Chiller††	2	8 (2.3)	0.57	12.7 (3.7)	8/14/ 9	14,556
Cooling Tower	3	36 (10.6)	0.46	92.8 (27.2)	9/ 4/ 9	15,881
Hot Water Tank	1	20 (5.9)	0.10	19.4 (5.7)	9/29/14	964
Cold Water Tank	1	8 (2.3)	0.28	7.3 (2.1)	10/20/ 5	8,132
		Configuration A-4 (Gas Turbine)				
Gas Turbine	2*	45 (13.2)	0.58	88.7 (26.0)	9/ 9/15	15,802
Boiler	3	50 (14.7)	0.55	132.4 (38.8)	1/31/ 7	1,198
	1**	30 (8.8)	0.55	132.4 (38.8)	1/31/ 7	2,868
Absorption Chiller††	2	8 (2.3)	0.67	15.1 (4.4)	8/14/11	17,520
Cooling Tower	2	36 (10.6)	0.79	72.0 (21.1)	12/13/17	16,166

*Plus one reserve unit.

**On reserve.

†Dual stage.

††Single stage.

Table 12
CMA Energy Plant Equipment Utilization

Equipment	Number	Size MBtuh (MW)	Average Operating Ratio	Maximum Load MBtuh (MW)	Maximum Load Date mo/da/hr	Operating Hours
		Configuration C-1 (Boiler Plant)				
Boiler	4	26 (7.6)	0.66	60.9 (17.8)	1/31/ 9	13,887
Absorption Chiller*	1	12 (3.5)	0.94	12.0 (3.5)	8/31/24	2,208
		Configuration C-2 (Diesel)				
Diesel	2*	22 (6.4)	0.55	43.4 (12.7)	9/11/14	14,297
Boiler	2*	24 (7.0)	0.33	42.8 (12.5)	1/31/ 7	5,339
Absorption Chiller**	1	12 (3.5)	0.94	12.0 (3.5)	8/31/24	2,208
Cooling Tower	4	12 (3.5)	0.48	47.2 (13.8)	9/11/15	20,194
		Configuration C-3 (Diesel With Thermal Storage)				
Diesel	2*	22 (6.4)	0.55	43.4 (12.7)	9/11/14	14,277
Boiler	2*	24 (7.0)	0.32	42.8 (12.5)	1/31/ 7	5,334
Absorption Chiller**	1	12 (3.5)	0.76	11.1 (3.3)	7/26/ 9	2,192
Cooling Tower	4	12 (3.5)	0.45	47.2 (13.8)	9/11/15	19,241
Hot Water Tank	1	8 (2.3)	0.10	6.9 (2.0)	4/10/ 1	1,626
Cold Water Tank	1	11 (3.2)	0.04	10.2 (3.0)	6/30/8	2,210
		Configuration C-4 (Gas Turbine)				
Gas Turbine	2*	22 (6.4)	0.55	43.0 (12.6)	9/11/14	14,385
Boiler	2*	24 (7.0)	0.34	38.6 (11.3)	1/31/ 7	1,985
Absorption Chiller†	1	12 (3.5)	0.94	12.0 (3.5)	8/31/24	2,208
Cooling Tower	3	12 (3.5)	0.82	36.0 (10.6)	12/25/ 9	22,123

*Plus one reserve unit.

**Single stage.

†Dual stage.

Table 15 summarizes Table 10 to compare results of regional and central energy plants. The data listed for each category of regional plant are summations over the four regional plants modeled. Central plant data are repeated from Table 10. Table 16 uses information from Table 15 to rank energy plants in order of energy consumed. The existing regional boiler plants appear to be the least energy-consumptive. However, when the thermal energy wasted by the utility in producing electricity is added to the listed energy, the rank changes from first to seventh. For the same reason, the central boiler plant rank shifts to eighth. In terms of total fuel efficiency, then, the central diesel plant with thermal storage is the least energy-consumptive. A central diesel plant without storage would actually rank second. The third would be regional diesel plants with thermal storage. Clearly, thermal storage can be quite beneficial. A central gas turbine would rank fifth. These results clearly indicate that central TE plants would be less energy-consumptive than regional plants.

Table 13
Laundry Energy Plant Equipment Utilization

Equipment	Number	Size MBtuh (MW)	Average Operating Ratio	Maximum Load MBtuh (MW)	Maximum Load Date mo/da/hr	Operating Hours
		Configuration L-1 (Boiler Plant)				
Boiler	1	25 (7.3)				0
	1	37.8 (11.1)	.52	31.0 (9.1)	12/31/ 9	3,132
		Configuration L-2 (Diesel)				
Diesel	2*	14 (4.1)	0.35	26.9 (7.9)	2/ 5/ 9	11,371
Boiler	1*	16 (4.7)	0.52	12.7 (3.7)	1/ 8/ 9	3,045
Cooling Tower	1	24 (7.0)	0.24	18.8 (5.5)	2/ 5/10	8,755
		Configuration L-3 (Diesel With Thermal Storage)				
Diesel	2*	14 (4.1)	0.35	26.9 (7.9)	2/ 5/ 9	11,371
Boiler	1*	16 (4.7)	0.52	12.7 (3.7)	1/ 8/ 9	3,045
Cooling Tower	1	24 (7.0)	0.24	18.8 (5.5)	2/ 5/10	8,755
Hot Water Tank	1	1 (0.3)	0.50	0.9 (0.3)	1/ 1/17	2
		Configuration L-4 (Gas Turbine)				
Gas Turbine	2*	14 (4.1)	0.35	26.8 (7.9)	1/24/ 9	11,496
Boiler	1*	16 (4.7)	0.0	0. (0)	–	0

*Plus one reserve unit.

Table 17 uses information from Table 15 to rank energy plants by life-cycle cost. The existing regional boiler plants are the lowest in life-cycle cost, followed by a central gas turbine plant using natural gas, and then a central boiler plant. The least energy-consumptive plant (accounting for thermal energy waste at the electric utility), a central diesel plant with thermal storage, is fourth on the list, having a life-cycle cost in excess of $400 million. Gas turbine plants using natural gas rank ahead of those using oil because of the difference in fuel cost (Table 8). When thermal storage is managed at the central rather than regional level, the increased energy efficiency more than compensates for the increased facilities cost (ranks 4 and 5 compared to ranks 7 and 9). The costliest energy plants appear to be regional ones with gas turbines using oil.

Tables 16 and 17 show that a single central TE plant is advantageous over regional TE plants in terms of both energy consumption and life-cycle cost. This result is primarily because economies of scale in prime movers and secondarily because of increased load diversity over regional plants.

Table 14
Central Total Energy Plant Equipment Utilization

Equipment	Number	Size MBtuh (MW)	Average Operating Ratio	Maximum Load MBtuh (MW)	Maximum Load Date (mo/da/hr)	Operating Hours
			Configuration P-1 (Boiler Plant)			
Boiler	1	1000 (293.1)	0.15	325.9 (95.5)	1/31/ 9	8,760
Absorption Chiller†	1	100 (29.3)	0.20	34.7 (10.2)	8/14/11	8,760
			Configuration P-2 (Diesel)			
Diesel	2*	85 (24.9)	0.62	169.3 (49.6)	9/28/13	16,398
Boiler	2*	120 (35.2)	0.30	210.7 (61.8)	1/31/ 7	6,953
Absorption Chiller**	3	12 (3.5)	0.73	34.7 (10.2)	8/14/11	17,704
Compression Chiller	1	12 (3.5)				1,146
	1	8 (2.3)	0.63	18.3 (5.4)	11/24/11	1,579
Cooling Tower	3	100 (106)	0.42	182.1 (53.4)	9/18/17	14,834
			Configuration P-3 (Diesel With Thermal Storage)			
Diesel	2*	85 (24.9)	0.61	166.6 (48.8)	9/28/12	16,358
Boiler	2*	120 (35.2)	0.29	210.7 (61.8)	1/31/ 7	7,013
Absorption Chiller**	3	12 (3.5)	0.60	29.0 (8.5)	8/14/14	14,838
Compression Chiller	1	12 (3.5)				1,068
	1	8 (2.3)	0.61	17.8 (5.2)	11/24/ 9	1,495
Cooling Tower	2	100 (29.3)	0.39	177.4 (52.0)	9/13/16	12,388
Hot Water Tank	1	31 (9.1)	0.11	27.9 (8.2)	9/29/14	716
Cold Water Tank	1	16 (4.7)	0.24	13.5 (4.0)	12/13/23	7,823
			Configuration P-4 (Gas Turbine)			
Gas Turbine	2*	85 (24.9)	0.61	164.3 (48.2)	9/28/12	16,321
Boiler	2*	120 (35.2)	0.36	205.6 (60.3)	1/31/ 7	2,978
Absorption Chiller**	3	12 (3.5)	0.73	34.7 (10.2)	8/14/11	18,618
Compression Chiller	1	12 (3.5)				608
	1	8 (2.3)	0.61	18.0 (5.3)	11/30/ 1	908
Cooling Tower	1	100 (29.3)	0.76	100.0 (29.3)	12/31/17	8,760
			Configuration P-5 (Diesels With Decentralized Cooling)			
Diesel	3	85 (24.9)	0.57	166.8 (48.9)	9/26/12	17,524
Boiler	2	120 (35.2)	0.39	240.0 (70.3)	1/31/ 7	8,382
Absorption Chiller**	1	12 (3.5)				2,208
	3	8 (2.3)	0.73	34.7 (10.2)	8/14/11	24,941
Compression Chiller	1	4 (1.2)	0.95	4.0 (1.2)	12/30/ 6	1,994
Cooling Tower	2	100 (29.3)				13,735
	2	28 (8.2)	0.46	161.1 (47.2)	6/ 6/18	0
	1	40 (11.7)				0

*Plus one reserve unit.

**Single stage.

Table 15
Central and Total of Regional Plant Energy Consumption and Life-Cycle Costs

Primer Mover	Annual Energy Consumption, GBtu (TJ) Oil Diesel	Oil Turbine	Natural Gas Turbine	Natural Gas Boiler	Electricity*	Total	Equipment Cost in 25 Years, M$	Life Cycle Cost in 25 Years, M$
Boiler (Regional)	–	–	–	1654 (1745)	832 (878)	2486 (2623)	27.59	368.96*
Diesel (Regional	2695 (2843)	–	–	407 (429)	–	3102 (3272)	87.48	474.30
Diesel with Thermal Storage (Regional)	2678 (2825)	–	–	398 (420)	–	3076 (3245)	85.88	555.44
Gas Turbine on Natural Gas (Regional)		–	3734 (3939)	185 (195)	–	3919 (4134)	93.31	432.52
Gas Turbine on Oil (Regional)	–	3734 (3939)	–	185 (195)	–	3919 (4134)	93.31	596.52
Boiler (Central)	–	–	–	2338 (2467)	832 (878)	3170 (3344)	12.08	396.79*
Diesel (Central)	2648 (2794)	–	–	378 (399)	–	3028 (3192)	45.95	424.11
Diesel with Thermal Storage (Central)	2626 (2770)	–	–	372 (392)	–	2998 (3163)	45.22	419.99
Gas Turbine on Natural Gas (Central)	–	–	3503 (3696)	188 (198)	–	3691 (3894)	50.12	369.62
Gas Turbine on Oil (Central)	–	3503 (3696)	–	188 (198)	–	3691 (3894)	50.12	523.46

*Does not represent fuel energy wasted by utility to make electricity.

Table 16
Ranking of Energy Plants by Energy Consumed

Rank	Plant	Energy, GBtu (TJ)
1	Boiler (Regional)	2486 (2623)*
2	Diesel with Thermal Storage (Central)	2998 (3163)
3	Diesel (Central)	3028 (3192)
4	Diesel with Thermal Storage (Regional)	3076 (3245)
5	Diesel (Regional)	3102 (3272)
6	Boiler (Central)	3170 (3344)*
7	Gas Turbine (Central)	3691 (3894)
8	Gas Turbine (Regional)	3919 (4134)

*Does not represent fuel energy wasted by utility to make electricity.

Table 17
Ranking of Energy Plants by Life-Cycle Cost

Rank	Plant	Life-Cycle Cost in 25 Years, M$
1	Boiler (Regional)	368.96*
2	Gas Turbine on Natural Gas (Central)	369.62
3	Boiler (Central)	396.79*
4	Diesel with Thermal Storage (Central)	419.99
5	Diesel (Central)	424.11
6	Gas Turbine on Natural Gas (Regional)	432.52
7	Diesel (Regional)	474.30
8	Gas Turbine on Oil (Central)	523.46
9	Diesel with Thermal Storage (Regional)	555.44
10	Gas Turbine on Oil (Regional)	596.52

*Does not represent fuel energy wasted by utility to make electricity.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions were drawn based on the study results:

1. Many Army installations have sufficient thermal demand to justify considering centralized TE applications for a large portion of each installation. In addition, enough large heating plants exist at most installations so that implementing a central TE system might require only minor additions to the thermal distribution systems.

2. The method for assessing candidate regional and central plants presented in this report is viable. The method considers both energy and life-cycle costs of the plant.

3. Central TE plants can be shown to be economically advantageous over regional TE plants, mostly because of economies of scale in prime movers. Added load diversity beyond that available to regional plants provides a secondary benefit.

4. Peak shaving by thermal storage is beneficial for large diesel plants.

5. The most fuel-efficient plants are central plants using diesel engines with thermal storage. Central diesel plants without storage are second. Regional diesel plants, and central and regional gas turbine plants follow in order of decreasing fuel efficiency.

6. The plants having the lowest life-cycle cost are central plants using gas turbines on natural gas, as long as gas maintains its current price structure. Central diesel plants with thermal storage are next, followed by central diesel plants without thermal storage. Regional gas turbine plants on natural gas (presuming current gas price structure) and diesel plants, central gas turbine plants on oil, regional diesel plants with thermal storage, and regional gas turbine plants on oil conclude the list.

Recommendations

The concept of a centralized TE system for military installations should be considered when (1) a TE study is being made in conjunction with a new construction project in accordance with the DoD directive,[16] (2)

[16] *Modification of DoD Construction Criteria Manual 4270.1-M* (Department of Defense, 13 September 1974).

several new construction projects are scheduled for one installation during a relatively short time period (3 to 5 years), or (3) an existing boiler plant is to be expanded or have a major boiler retrofit.

It is recommended that the method described in this report, including use of the CEPS portion of the BLAST program to simulate central and regional TE plants, be used to assist installations and Corps Districts in immediate and long-range planning and design of energy plants.

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APPENDIX A:

ANALYSIS AND SYNTHESIS OF ENERGY DEMANDS

The method of central TE plant analysis presented in Chapter 3 requires determination of the load for each load center. This appendix provides a procedure for determining this load using metered data.

Electrical Load

This procedure assumes that any post large enough to be considered for central TE is also a sufficiently large electrical user to be subject to electrical demand charges. Two general types of demand meters are commonly used: interval demand recorders (recording, for example, every 15 minutes) and integrating demand meters (which provide a single peak demand each month). The type of meter present determines the data structure available, and thus the load-determining technique.

Interval Demand Recorders

This technique assumes that all electric power passes through demand recorders from which hourly (or subhourly) data are available. The hourly electrical load is then the sum of the recorded demands each hour.

Alternatively, a smaller data base can be used by using design weeks and the procedure in the following section.

Interval Demand Recorders With Integrating Demand Meters

This technique assumes that some electric power passes through one demand recorder, from which hourly (or subhourly) data are available, while the balance of the power passes through an integrating demand meter. The hourly data were used to partition the monthly data into design weekdays and weekends for three seasons: summer (June-August), winter (December-February), and spring/fall (March-May, September-November). This was accomplished by determining some scale factors that change monthly and others that change seasonally.

The procedure is as follows:

1. Choose a 2-week sample from the hourly data for each of the three seasons, obtaining three samples.

2. Determine the average weekday load per sample (D) by summing the sample weekday loads and dividing by 10. This yields three values.

3. Determine the average load for each weekend day per sample (E) by summing the sample weekend loads and dividing by 4. This yields three values.

4. Compute the average sample daily load per sample (d) as:

$$d = [(5 \times D) + (2 \times E)]/7$$

This yields three values.

5. Compute the weekday scale factor per sample (S_D) by dividing D by d. This yields three values.

6. Compute the weekend scale factor per sample (S_E) by dividing E by d. This yields three values.

7. Determine the average demand each weekday hour of the sample (H_D) by summing the demands during the given hour over the sample weekdays and dividing by 10. This yields 24 values per sample or a total of 72 values.

8. Determine the average demand each weekend hour of the sample (H_E) by summing the demands during the given hour over the sample weekend and by dividing by 4. This yields 24 values per sample or a total of 72 values.

9. Compute the weekday hourly scale factor per sample (S_{HD}) by dividing H_D by D. This yields 72 values.

10. Compute the weekend hourly scale factor per sample (S_{HE}) by dividing H_E by E. This yields 72 values.

11. Determine the average daily consumption per month (D_M) by dividing the total monthly consumption from all meters by the number of days per month. This yields 12 values.

12. Compute the hourly electrical load for a weekday in each month (L_D) by multiplying D_M by S_{HD} by S_D. This yields 24 values per month, 288 values per year.

13. Compute the hourly electrical load for a weekend in each month (L_E) by multiplying D_M by S_{HE} by S_E. This yields 24 values per month, 288 values per year.

14. Construct the hourly electrical load over the year by using L_D or L_E values, as appropriate, for each day. The hourly electrical load calculated in this step is inserted into the CEPS program.

Integrating Demand Meters

In this instance, electrical consumption is known only monthly. The procedure is as follows:

1. Obtain hourly electrical demand readings over a 2-week period for the current season, since 2 weeks can almost always be spared for metering in current project.

2. Follow the procedure in the preceding section to obtain hourly values for the current season.

3. Use the standard values and profiles from Tables A1 through A3 and monthly consumption records to determine hourly values for the out-of-season months, following steps 11 through 14 of the procedure above.

Thermal Load

Metered thermal data is most readily available in the form of hourly boiler logs at boiler plants, making it extremely convenient to identify the distribution system of a boiler plant as a thermal load center. The procedure for determining the load for thermal load centers so defined is as follows:

1. Determine the hourly steam load in each boiler plant for the year using boiler logs; **OR**

2. a. Determine the hourly steam load in each boiler plant for each design sample, using boiler logs.

b. Follow steps 1 through 3 and 7 through 9 of the 14-step procedure above.

c. Determine daily totals of steam production over the year.

d. Determine the least-squares correlation $f_y^x(T)$ between daily steam production and daily mean temperature for each boiler plant (x) each season (y).*

e. Determine cooling load per plant (usually a seasonal constant known by operating personnel).

f. Determine steam users load by multiplying the average daily steam generation over successive warm days for which the mean temperature was greater than 76°F (24°C) by the hourly scale factor, and subtracting the cooling load from the product.

g. Determine heating load by multiplying $f_y^x(T)$ by the hourly scale factor and subtracting the sum of the steam users load and the cooling load.

h. Insert the cooling, steam users, and heating loads into the CEPS program as the thermal loads.

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*Seasonal designations are: s - summer; w - winter; sf - spring/fall.

Table A1
Scale Factor to Adjust Average Daily Electrical Load
(Unique for Each Month)
for Weekday/Weekend Differences

	Weekday, S_D	Weekend, S_E
Winter	1.073	0.924
Spring/Fall	1.182	0.818
Summer	1.070	0.929

Table A2
Hourly Weekday Electrical Scale Factors, S_{HD} (%)

Hour of Day	Winter	Spring/Fall	Summer
1	3.4	3.2	3.4
2	3.1	2.9	3.1
3	3.0	2.8	2.9
4	2.9	2.6	2.8
5	2.8	2.6	2.7
6	3.0	2.7	2.7
7	3.1	3.1	3.0
8	4.1	3.8	3.3
9	5.1	4.7	4.2
10	5.2	4.9	4.5
11	5.2	5.1	4.8
12	5.2	5.2	5.1
13	5.2	5.2	5.1
14	5.1	5.2	5.3
15	4.7	5.2	5.3
16	4.7	5.2	5.4
17	4.6	5.0	5.3
18	3.9	4.5	4.9
19	4.1	4.4	4.6
20	4.8	4.5	4.5
21	4.6	4.5	4.3
22	4.5	4.6	4.4
23	4.2	4.4	4.2
24	3.6	3.9	4.0

Table A3
Hourly Weekend Electrical Scale Factors, S_{HE} (%)

Hour of Day	Winter	Spring/Fall	Summer
1	4.0	3.9	4.3
2	3.7	3.7	4.0
3	3.5	3.4	3.7
4	3.4	3.7	3.6
5	3.3	3.2	3.5
6	3.3	3.1	3.4
7	3.4	3.2	3.4
8	3.5	3.3	3.4
9	3.6	3.5	3.5
10	4.0	3.9	3.8
11	4.3	3.5	4.3
12	4.5	4.4	4.6
13	4.6	4.8	4.8
14	4.6	4.9	4.9
15	4.6	4.9	4.7
16	4.5	4.9	4.5
17	4.5	4.9	4.5
18	4.4	4.8	4.6
19	4.7	4.9	4.5
20	5.0	4.7	4.4
21	4.8	4.8	4.3
22	4.6	4.9	4.5
23	4.6	4.7	4.3
24	4.4	4.4	4.1

APPENDIX B: ENERGY UTILIZATION SUMMARIES

This appendix presents the monthly energy utilization summaries for the Fort Bragg case study.

Table B1
Central Plant Energy Utilization Summary—Configuration H-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	29.356	13.653	2.009	.025	0.000	3.863	.069	40.345	45.508	43.100	88.608	49.
2	25.646	14.831	1.814	.022	0.000	3.480	.062	35.202	49.436	37.684	87.120	46.
3	28.051	13.978	5.357	.025	0.000	5.375	.069	38.752	46.595	41.518	88.113	48.
4	22.135	15.160	5.184	.024	0.000	5.140	.066	30.228	50.533	32.873	83.406	45.
5	15.128	16.607	5.357	.025	0.000	5.400	.069	20.956	55.356	23.735	79.091	40.
6	14.452	20.518	5.184	.024	0.000	5.249	.066	20.119	68.393	22.819	91.213	38.
7	14.935	20.333	5.357	.025	0.000	5.441	.069	20.856	67.778	23.655	91.433	39.
8	14.938	20.703	5.357	.025	0.000	5.438	.069	20.847	69.009	23.646	92.655	38.
9	15.930	25.590	5.184	.024	0.000	5.205	.066	21.940	85.299	24.617	109.916	38.
10	22.832	16.139	5.357	.025	0.000	5.306	.069	31.138	53.797	33.869	87.666	44.
11	26.309	14.611	5.184	.024	0.000	5.178	.066	36.208	48.703	38.873	87.575	47.
12	28.275	13.861	2.009	.025	0.000	3.871	.069	38.967	46.203	41.726	87.929	48.
	257.989	205.983	53.352	.290	0.000	58.944	.807	355.559	686.611	388.114	1074.725	43.

Table B2
Central Plant Energy Utilization Summary—Configuration H-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	28.367	13.869	2.009	18.969	.937	2.460	.244	37.930	18.389	59.008	59.008	72.
2	25.005	15.093	1.814	19.340	2.399	2.663	.186	34.145	20.946	57.588	57.588	70.
3	29.887	14.616	5.357	20.943	.561	7.615	.440	39.671	19.082	61.413	61.413	72.
4	25.224	15.797	5.184	21.581	2.278	9.526	.171	34.554	21.593	58.825	58.825	70.
5	18.905	17.399	5.357	19.088	7.205	11.859	.069	29.136	26.837	59.063	59.063	61.
6	18.107	21.431	5.184	19.412	11.205	12.173	.072	29.636	35.219	68.027	68.027	58.
7	18.712	21.141	5.357	19.864	10.757	12.453	.073	30.316	34.404	67.964	67.964	59.
8	18.715	21.508	5.357	19.985	11.076	12.509	.074	30.458	35.119	68.836	68.836	58.
9	19.586	26.628	5.184	21.377	15.143	12.601	.075	32.911	45.680	81.871	81.871	56.
10	26.083	16.807	5.357	22.764	2.550	9.941	.166	35.822	23.042	61.638	61.638	70.
11	28.661	15.222	5.184	22.032	.819	8.185	.314	38.206	19.982	60.775	60.775	72.
12	27.568	14.047	2.009	19.347	.794	2.822	.205	36.705	18.513	57.892	57.892	72.
	284.820	213.558	53.352	244.701	65.723	104.808	2.088	409.489	318.805	762.902	762.902	66.

Table B3
Central Plant Energy Utilization Summary—Configuration H-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	28.981	13.933	2.009	19.314	.710	1.919	.232	38.587	18.364	58.933	58.933	73.
2	26.396	15.089	1.814	19.739	2.027	1.616	.162	35.802	20.780	57.327	57.327	72.
3	30.428	14.582	5.357	21.283	.153	7.079	.418	40.060	18.829	60.931	60.931	74.
4	26.964	15.662	5.184	21.880	1.704	7.265	.157	36.580	21.118	58.002	58.002	73.
5	23.421	17.076	5.357	19.234	6.623	5.610	.061	35.347	26.170	58.268	58.268	70.
6	22.581	21.108	5.184	19.607	10.728	5.508	.063	36.307	34.542	67.296	67.296	65.
7	23.336	20.841	5.357	20.083	10.325	5.661	.065	37.142	33.808	67.335	67.335	66.
8	23.313	21.221	5.357	20.175	10.573	5.706	.065	37.254	34.496	68.148	68.148	65.
9	25.007	26.265	5.184	21.613	14.428	5.514	.066	41.269	44.715	80.813	80.813	63.
10	27.986	16.660	5.357	23.124	1.981	7.484	.154	38.095	22.546	60.778	60.778	73.
11	29.390	15.162	5.184	22.431	.310	7.342	.293	38.768	19.643	60.100	60.100	74.
12	28.204	14.103	2.009	19.675	.481	2.260	.191	37.318	18.435	57.722	57.722	73.
	316.007	211.702	53.352	248.157	60.042	62.963	1.928	452.529	313.445	755.652	755.652	70.

Table B4
Central Plant Energy Utilization Summary–Configuration H-4
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	28.944	14.077	2.009	23.836	11.196	3.880	.192	46.058	23.447	72.732	72.732	59.
2	25.587	15.168	1.814	22.679	10.831	4.402	.107	44.022	27.910	75.117	75.117	54.
3	31.244	14.485	5.357	26.221	7.009	11.354	.216	49.771	23.776	76.746	76.746	60.
4	25.709	15.615	5.184	25.278	16.263	13.291	.098	45.441	28.773	77.689	77.689	53.
5	18.905	17.085	5.357	20.903	36.234	16.215	.095	39.641	36.911	80.741	80.741	45.
6	18.107	20.979	5.184	20.047	30.712	16.598	.098	40.315	47.131	91.754	91.754	43.
7	18.712	20.806	5.357	20.717	33.095	17.101	.101	41.520	46.794	92.750	92.750	43.
8	18.715	21.174	5.357	20.721	32.647	17.089	.101	41.490	47.411	93.332	93.332	43.
9	19.586	26.052	5.184	21.525	28.806	15.897	.095	41.787	55.511	101.465	101.465	45.
10	26.496	16.614	5.357	26.340	17.937	13.816	.111	47.437	30.953	82.018	82.018	53.
11	29.659	15.076	5.184	26.904	8.497	11.975	.149	49.423	25.852	78.513	78.513	57.
12	28.220	14.318	2.009	24.358	13.908	4.440	.107	44.919	23.606	71.746	71.746	59.
	289.884	211.450	53.352	279.529	247.135	146.059	1.471	531.823	418.076	994.603	994.603	51.

Table B5
Central Plant Energy Utilization Summary–Configuration A-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	68.971	30.587	7.931	.117	0.000	8.695	.416	97.375	101.957	105.691	207.648	48.
2	58.231	30.797	7.164	.106	0.000	7.939	.376	82.877	102.657	90.470	193.127	46.
3	58.236	30.427	7.931	.117	0.000	8.623	.416	82.010	101.422	90.261	191.683	46.
4	41.277	29.790	7.675	.114	0.000	8.436	.402	58.262	99.300	66.331	165.631	43.
5	28.831	31.772	7.931	.117	0.000	9.220	.416	43.226	105.906	52.034	157.940	38.
6	26.204	38.992	7.690	.114	0.000	9.088	.402	39.871	129.972	48.518	178.489	37.
7	27.159	38.568	7.995	.117	0.000	9.548	.416	41.450	128.561	50.411	178.972	37.
8	27.556	39.280	8.264	.117	0.000	10.133	.416	41.922	130.935	50.852	181.787	37.
9	29.709	44.275	7.675	.114	0.000	8.881	.402	44.211	147.583	52.705	200.287	37.
10	43.257	32.548	7.931	.117	0.000	8.710	.416	61.054	108.492	69.381	177.873	43.
11	50.639	29.604	7.675	.114	0.000	8.258	.402	70.420	98.679	78.318	176.997	45.
12	63.608	30.440	7.931	.117	0.000	8.689	.416	90.128	101.466	98.444	199.911	47.
	523.678	407.079	93.793	1.381	0.000	106.219	4.896	752.804	1356.931	853.416	2210.347	42.

Table B6
Central Plant Energy Utilization Summary—Configuration A-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	73.815	30.949	7.931	43.927	2.090	14.801	.121	99.081	40.823	145.019	145.019	72.
2	62.605	31.195	7.164	41.757	3.045	13.604	.111	84.751	41.896	131.351	131.351	71.
3	63.080	30.733	7.931	43.394	1.581	14.770	.120	84.799	40.309	130.214	130.214	72.
4	45.964	30.305	7.675	39.425	4.644	14.832	.121	63.569	41.726	110.426	110.426	69.
5	33.675	32.695	7.931	33.707	13.209	16.962	.140	51.917	50.572	108.352	108.352	61.
6	30.887	40.066	7.690	33.327	21.295	17.713	.147	51.350	66.907	124.367	124.367	57.
7	31.987	39.631	7.995	34.021	20.047	18.122	.149	52.279	65.245	123.728	123.728	58.
8	32.385	40.346	8.264	34.756	20.710	18.893	.150	53.262	66.564	126.069	126.069	58.
9	34.397	45.331	7.675	37.301	24.153	17.748	.147	57.227	76.557	139.926	139.926	57.
10	48.100	33.104	7.931	42.016	5.216	15.305	.125	66.511	45.726	117.528	117.528	69.
11	55.326	29.923	7.675	42.182	1.628	14.302	.116	74.392	39.329	118.663	118.663	72.
12	68.452	30.802	7.931	43.899	1.891	14.761	.120	91.813	40.529	137.448	137.448	72.
	580.673	415.079	93.793	469.711	119.509	191.814	1.566	830.953	616.183	1513.091	1513.091	66.

Table B7
Central Plant Energy Utilization Summary—Configuration A-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	75.734	30.680	7.931	45.056	.387	12.345	.115	100.462	39.668	142.766	142.766	75.
2	65.058	30.877	7.164	42.824	1.580	10.461	.101	87.120	40.707	129.300	129.300	74.
3	64.653	30.538	7.931	44.545	.152	12.719	.116	85.794	39.351	128.213	128.213	74.
4	49.010	29.989	7.675	40.136	3.566	11.019	.102	67.074	40.759	108.916	108.916	73.
5	39.278	32.210	7.931	33.931	12.381	9.706	.095	59.846	49.487	107.262	107.262	67.
6	37.146	39.647	7.690	33.741	20.509	8.735	.096	60.940	65.800	123.426	123.426	62.
7	37.629	39.198	7.995	34.362	19.340	10.049	.098	60.747	64.207	122.778	122.778	63.
8	38.208	39.899	8.264	35.084	20.002	10.428	.102	62.079	65.506	125.078	125.078	62.
9	42.485	44.940	7.675	37.662	23.280	9.134	.096	70.025	75.363	138.863	138.863	63.
10	51.753	32.728	7.931	42.776	4.088	10.926	.104	70.853	44.642	115.899	115.899	73.
11	57.077	29.729	7.675	43.206	.335	12.096	.111	75.724	38.417	116.835	116.835	74.
12	70.205	30.532	7.931	44.984	.306	12.512	.116	93.111	39.414	135.364	135.364	74.
	628.237	410.966	93.793	478.308	105.925	130.129	1.251	893.776	603.321	1494.700	1494.700	69.

Table B8
Central Plant Energy Utilization Summary—Configuration A-4
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	73.815	30.893	7.931	56.027	4.407	17.930	.156	119.578	52.746	178.512	178.512	59.
2	62.605	31.116	7.164	51.799	8.551	16.698	.142	102.453	53.229	161.450	161.450	58.
3	63.080	30.741	7.931	54.547	5.255	17.986	.153	102.856	51.494	160.570	160.570	58.
4	45.964	30.230	7.675	45.639	20.026	18.948	.158	80.760	54.966	142.278	142.278	54.
5	33.675	32.324	7.931	37.339	41.211	22.009	.183	67.306	66.339	141.238	141.238	47.
6	30.887	39.551	7.690	34.563	43.643	22.425	.186	64.924	82.743	155.386	155.386	45.
7	31.987	39.196	7.995	35.784	46.619	22.779	.188	65.502	81.029	154.291	154.291	46.
8	32.385	39.894	8.264	36.180	45.015	23.989	.191	67.617	82.924	158.465	158.465	46.
9	34.397	44.827	7.675	38.073	43.196	21.618	.180	69.588	90.339	167.397	167.397	47.
10	48.100	32.992	7.931	47.697	20.321	19.498	.163	84.131	59.562	150.427	150.427	54.
11	55.326	29.976	7.675	51.237	8.562	17.820	.150	92.269	51.098	149.524	149.524	57.
12	68.452	30.764	7.931	55.742	3.848	18.082	.155	111.804	52.210	170.261	170.261	58.
	580.673	412.504	93.793	544.628	290.654	239.785	2.004	1028.789	778.679	1889.799	1889.799	52.

Table B9
Central Plant Energy Utilization Summary—Configuration C-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	25.332	12.485	0.000	.019	0.000	0.000	0.000	34.275	41.616	36.367	77.983	48.
2	21.624	13.168	0.000	.017	0.000	0.000	0.000	29.094	43.892	30.973	74.865	46.
3	21.856	12.351	0.000	.019	0.000	0.000	0.000	29.774	41.170	31.879	73.049	47.
4	14.156	11.623	0.000	.018	0.000	0.000	0.000	19.237	38.744	21.269	60.012	43.
5	8.748	12.698	0.000	.019	0.000	0.000	0.000	12.435	42.328	14.631	56.959	38.
6	19.898	16.028	8.100	.018	0.000	16.277	.221	27.726	53.427	29.806	83.233	43.
7	20.561	15.883	8.370	.019	0.000	16.873	.228	28.741	52.942	30.897	83.839	43.
8	20.561	16.179	8.370	.019	0.000	16.863	.228	28.724	53.931	30.878	84.809	43.
9	9.317	19.557	0.000	.018	0.000	0.000	0.000	13.084	65.189	15.190	80.379	36.
10	15.036	12.723	0.000	.019	0.000	0.000	0.000	20.388	42.409	22.484	64.892	43.
11	18.378	11.805	0.000	.018	0.000	0.000	0.000	25.071	39.351	27.105	66.456	45.
12	23.575	12.460	0.000	.019	0.000	0.000	0.000	31.995	41.532	34.093	75.625	48.
	219.043	166.959	24.840	.223	0.000	50.013	.678	300.544	556.531	325.571	832.102	44.

Table B10

Central Plant Energy Utilization Summary—Configuration C-2

(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	25.332	12.645	0.000	17.711	1.304	0.000	0.000	34.473	17.003	53.393	53.593	71.
2	21.624	13.371	0.000	17.195	2.578	0.000	0.000	30.046	18.858	50.882	50.882	69.
3	21.856	12.516	0.000	17.528	1.574	0.000	0.000	30.110	16.949	49.202	49.202	70.
4	14.156	11.943	0.000	13.280	5.042	0.000	0.000	21.632	18.734	42.724	42.724	61.
5	8.743	13.258	0.000	8.920	11.244	0.000	0.000	16.709	25.686	45.351	45.351	49.
6	19.898	16.580	8.100	20.397	2.940	16.354	.092	27.860	23.068	53.018	53.018	69.
7	20.561	16.447	8.370	20.862	2.646	16.768	.094	28.568	22.683	53.394	53.394	69.
8	20.561	16.738	8.370	20.934	2.736	16.815	.094	28.646	23.130	53.925	53.925	69.
9	9.317	20.271	0.000	10.597	16.963	0.000	0.000	18.355	40.916	62.245	62.245	48.
10	15.036	13.065	0.000	14.243	5.478	0.000	0.000	22.984	20.481	45.901	45.901	61.
11	18.378	12.000	0.000	16.137	2.239	0.000	0.000	25.840	16.704	44.662	44.662	68.
12	23.575	12.613	0.000	17.719	1.223	0.000	0.000	32.076	16.884	51.071	51.071	71.
	219.043	171.446	24.840	195.522	55.967	49.937	.280	317.300	261.095	605.970	605.970	65.

Table B11

Central Plant Energy Utilization Summary—Configuration C-3

(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	5.424	12.644	0.000	17.721	1.294	.003	.000	34.606	16.995	53.582	53.582	71.
2	1.931	13.369	0.000	17.208	2.564	.003	.000	30.539	18.843	50.861	50.861	69.
3	1.924	12.515	0.000	17.547	1.562	0.000	0.000	30.196	16.940	49.178	49.178	70.
4	4.319	11.941	0.000	13.288	5.032	0.000	0.000	21.902	18.714	42.707	42.707	61.
5	8.815	13.257	0.000	8.929	11.235	0.000	0.000	16.828	25.672	45.349	45.349	49.
6	1.849	16.495	8.100	20.468	2.766	13.462	.090	30.363	22.896	52.629	52.629	73.
7	3.390	16.301	8.370	21.011	2.328	12.869	.092	32.147	22.332	52.828	52.828	75.
8	3.121	16.598	8.370	21.061	2.442	13.248	.093	31.881	22.799	53.377	53.377	74.
9	9.980	20.270	0.000	10.596	16.961	0.000	0.000	19.600	40.902	62.241	62.241	49.
10	5.282	13.064	0.000	14.244	5.477	0.000	0.000	23.380	20.478	45.884	45.884	62.
11	8.515	11.998	0.000	16.151	2.223	0.000	0.000	26.028	16.691	44.633	44.633	68.
12	3.654	12.612	0.000	17.728	1.213	0.000	0.000	32.183	16.876	51.055	51.055	71.
	8.204	171.064	24.840	195.953	55.096	39.585	.275	329.652	260.140	604.324	604.324	66.

Table B12
Central Plant Energy Utilization Summary – Configuration C-4
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	25.332	12.784	0.000	21.520	7.020	0.000	0.000	43.906	23.361	69.997	69.997	54.
2	21.624	13.469	0.000	20.379	7.700	0.000	0.000	39.187	25.940	67.747	67.747	52.
3	21.856	12.754	0.000	20.989	11.258	0.000	0.000	39.547	24.021	66.401	66.401	52.
4	14.156	12.205	0.000	15.278	27.693	0.000	0.000	29.517	27.250	59.993	59.993	44.
5	8.748	13.347	0.000	10.290	43.065	0.000	0.000	22.987	36.156	63.213	63.213	35.
6	19.898	16.403	8.100	21.356	15.251	21.283	.120	36.173	30.112	68.989	68.989	53.
7	20.561	16.267	8.370	22.026	15.763	22.168	.125	37.685	30.144	70.646	70.646	52.
8	20.561	16.564	8.370	22.084	16.281	21.848	.123	37.115	30.233	70.121	70.121	53.
9	9.317	20.183	0.000	10.810	30.037	0.000	0.000	22.984	49.864	76.566	76.566	39.
10	15.036	13.309	0.000	16.135	26.451	0.000	0.000	31.388	29.627	64.351	64.351	44.
11	18.378	12.313	0.000	18.643	14.860	0.000	0.000	34.915	24.423	62.213	62.213	49.
12	23.575	12.786	0.000	21.385	7.369	0.000	0.000	41.304	23.325	67.378	67.378	54.
	219.043	172.386	24.840	220.893	222.748	65.299	.368	416.707	354.455	807.614	807.614	48.

Table B13
Central Plant Energy Utilization Summary – Configuration L-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	5.513	5.513	0.000	.012	0.000	0.000	0.000	7.544	18.378	8.914	27.292	40.
2	4.794	4.794	0.000	.011	0.000	0.000	0.000	6.558	15.981	7.749	23.730	40.
3	5.307	5.307	0.000	.012	0.000	0.000	0.000	7.231	17.690	8.544	26.234	40.
4	3.799	3.799	0.000	.008	0.000	0.000	0.000	5.454	12.664	6.444	19.109	40.
5	3.699	3.699	0.000	.008	0.000	0.000	0.000	5.460	12.329	6.451	18.781	39.
6	3.374	3.374	0.000	.008	0.000	0.000	0.000	5.055	11.246	5.973	17.219	39.
7	5.302	5.302	0.000	.012	0.000	0.000	0.000	7.348	17.672	8.682	26.354	40.
8	2.771	2.771	0.000	.006	0.000	0.000	0.000	4.436	9.238	5.241	14.479	38.
9	2.412	2.412	0.000	.005	0.000	0.000	0.000	3.811	8.041	4.503	12.544	38.
10	5.086	5.086	0.000	.011	0.000	0.000	0.000	7.033	16.953	8.311	25.263	40.
11	5.307	5.307	0.000	.012	0.000	0.000	0.000	7.234	17.690	8.547	26.237	40.
12	5.034	5.034	0.000	.011	0.000	0.000	0.000	6.885	16.780	8.136	24.916	40.
	52.398	52.398	0.000	.117	0.000	0.000	0.000	74.047	174.661	87.496	262.156	40.

Table B14
Central Plant Energy Utilization Summary–Configuration L-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	5.513	5.829	0.000	3.790	4.786	0.000	0.000	6.976	11.751	22.357	22.357	51.
2	4.794	5.086	0.000	3.296	4. 7	0.000	0.000	7.804	10.315	19.536	19.536	51.
3	5.307	5.621	0.000	3.645	4.672	0.000	0.000	6.617	11.410	21.592	21.592	51.
4	3.799	4.107	0.000	2.656	3.898	0.000	0.000	6.393	8.776	16.325	16.325	48.
5	3.699	4.020	0.000	2.866	3.968	0.000	0.000	6.363	8.669	16.208	16.208	48.
6	3.374	3.680	0.000	2.473	3.786	0.000	0.000	5.891	8.098	15.059	15.059	47.
7	5.302	5.620	0.000	3.617	4.623	0.000	0.000	8.633	11.365	21.561	21.561	41.
8	2.771	3.069	0.000	2.043	3.257	0.000	0.000	4.952	6.966	12.757	12.757	46.
9	2.412	2.706	0.000	1.010	3.141	0.000	0.000	4.353	6.354	11.438	11.438	45.
10	3.000	5.400	0.000	3.491	4.530	0.000	0.000	8.290	11.065	20.001	20.001	50.
11	5.307	5.616	0.000	3.646	4.631	0.000	0.000	8.619	11.351	21.536	21.536	51.
12	5.034	5.344	0.000	3.459	4.512	0.000	0.000	8.193	10.937	20.618	20.618	50.
	52.398	56.100	0.000	36.621	50.042	0.000	0.000	87.063	116.953	219.653	219.653	49.

Table B15
Central Plant Energy Utilization Summary–Configuration L-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)
1	5.515	5.829	0.000	3.791	4.785	0.000	0.000	8.982	11.747	22.356	22.356
2	4.794	5.080	0.000	3.296	4.227	0.000	0.000	7.804	10.315	19.536	19.536
3	5.307	5.621	0.000	3.645	4.672	0.000	0.000	8.617	11.410	21.592	21.592
4	3.799	4.107	0.000	2.686	3.898	0.000	0.000	6.393	8.770	16.325	16.325
5	3.699	4.020	0.000	2.666	3.968	0.000	0.000	6.363	8.689	16.208	16.208
6	3.374	3.680	0.000	2.473	3.788	0.000	0.000	5.891	8.098	15.059	15.059
7	5.302	5.620	0.000	3.617	4.623	0.000	0.000	8.633	11.365	21.565	21.565
8	2.771	3.069	0.000	2.043	3.257	0.000	0.000	4.952	6.906	12.757	12.757
9	2.412	2.706	0.000	1.810	3.141	0.000	0.000	4.353	6.354	11.498	11.498
10	5.086	5.408	0.000	3.491	4.538	0.000	0.000	8.290	11.005	20.801	20.801
11	5.307	5.616	0.000	3.646	4.631	0.000	0.000	8.619	11.351	21.536	21.536
12	5.034	5.344	0.000	3.459	4.512	0.000	0.000	8.193	10.937	20.618	20.618
	52.400	56.100	0.000	36.622	50.041	0.000	0.000	87.090	116.950	219.853	219.853

Table B16
Central Plant Energy Utilization Summary–Configuration L-4
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	5.513	5.772	0.000	6.515	19.905	0.000	0.000	9.462	10.812	21.993	21.993	51.
2	4.794	5.027	0.000	5.665	17.899	0.000	0.000	8.203	9.437	19.130	19.130	51.
3	5.307	5.567	0.000	6.271	20.008	0.000	0.000	8.950	10.334	20.909	20.909	52.
4	3.799	4.103	0.000	4.489	23.352	0.000	0.000	7.104	8.658	17.052	17.052	46.
5	3.699	4.072	0.000	4.371	28.709	0.000	0.000	7.492	9.299	18.152	18.152	43.
6	3.374	3.784	0.000	3.987	31.538	0.000	0.000	7.223	9.125	17.659	17.659	41.
7	5.302	5.709	0.000	6.265	31.362	0.000	0.000	8.632	10.379	20.579	20.579	54.
8	2.771	3.098	0.000	3.275	25.095	0.000	0.000	6.704	8.256	16.177	16.177	36.
9	2.412	2.714	0.000	2.850	23.211	0.000	0.000	6.020	7.488	14.601	14.601	35.
10	5.086	5.406	0.000	6.010	24.612	0.000	0.000	8.627	10.171	20.365	20.365	52.
11	5.307	5.581	0.000	6.271	21.107	0.000	0.000	8.841	10.231	20.678	20.678	53.
12	5.034	5.287	0.000	5.948	19.500	0.000	0.000	8.547	9.943	20.074	20.074	51.
	52.398	56.120	0.000	61.915	286.299	0.000	0.000	95.832	114.132	227.370	227.370	47.

Table B17
Central Plant Energy Utilization Summary–Configuration P-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	139.195	62.252	9.940	.103	0.000	33.395	1.904	241.498	207.505	256.094	463.600	43.
2	119.150	63.576	8.978	.092	0.000	30.473	1.720	208.326	211.920	221.584	433.504	42.
3	126.008	62.140	13.288	.102	0.000	40.209	1.904	223.349	207.132	238.090	445.223	42.
4	93.518	60.354	12.859	.096	0.000	40.486	1.842	172.150	201.181	186.568	387.749	40.
5	68.955	64.757	13.288	.099	0.000	43.673	1.904	133.125	215.858	148.595	364.453	37.
6	73.480	78.814	20.974	.095	0.000	59.411	1.842	140.865	262.715	155.659	418.374	36.
7	77.800	80.045	21.722	.102	0.000	61.501	1.904	149.041	266.816	164.941	431.757	37.
8	75.579	78.887	21.991	.096	0.000	62.306	1.904	145.389	262.956	160.479	423.435	36.
9	69.520	91.834	12.859	.093	0.000	42.270	1.842	134.090	306.114	148.668	454.782	35.
10	98.760	66.470	13.288	.102	0.000	41.772	1.904	181.331	221.567	196.574	418.141	40.
11	112.785	61.351	12.859	.099	0.000	39.367	1.842	202.387	204.502	216.881	421.383	41.
12	130.587	61.809	9.940	.102	0.000	33.710	1.904	229.694	206.032	244.286	450.317	43.
	1185.336	832.289	171.985	1.180	0.000	528.573	22.417	2161.246	2774.298	2338.419	5112.717	39.

Table B18
Central Plant Energy Utilization Summary—Configuration P-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	128.399	63.669	9.940	87.113	4.220	11.426	1.143	174.245	84.402	270.045	270.045	71.
2	110.693	64.921	8.978	84.261	7.660	12.403	.816	151.910	88.398	250.762	250.762	70.
3	117.405	63.630	13.288	87.828	2.993	19.075	1.024	159.183	83.372	253.825	253.825	71.
4	88.464	62.064	12.859	77.329	11.241	24.183	.392	125.420	86.327	222.925	222.925	68.
5	64.920	67.080	13.288	63.676	30.061	29.942	.216	104.603	106.559	224.096	224.096	59.
6	72.079	81.894	20.974	76.704	33.886	46.736	.312	113.916	128.970	255.088	255.088	60.
7	76.373	82.690	21.722	79.625	32.603	48.019	.319	119.695	128.670	261.384	261.384	61.
8	74.269	81.492	21.991	78.893	32.219	48.603	.319	116.217	126.774	255.272	255.272	61.
9	65.616	95.123	12.859	71.812	57.458	31.456	.231	114.161	168.332	295.714	295.714	54.
10	93.647	68.232	13.288	83.591	11.687	25.109	.389	132.734	95.105	239.667	239.667	68.
11	106.180	62.742	12.859	85.675	3.532	20.894	.670	144.850	82.540	238.406	238.406	71.
12	121.077	63.054	9.940	87.490	3.779	13.080	.917	164.179	83.159	258.580	258.580	71.
	1119.121	856.591	171.985	963.998	231.338	330.926	6.748	1621.114	1262.610	3025.762	3025.762	65.

Table B19
Central Plant Energy Utilization Summary—Configuration P-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	131.187	63.472	9.940	88.438	2.731	8.920	1.065	177.093	83.362	268.654	268.654	72.
2	114.641	64.622	8.978	85.565	6.022	8.772	.706	156.431	87.073	249.250	249.250	72.
3	120.277	63.255	13.288	89.354	.515	16.179	.934	161.490	81.765	251.155	251.155	73.
4	93.883	61.411	12.859	78.304	8.778	17.106	.347	132.018	84.638	220.436	220.436	70.
5	73.975	66.347	13.288	63.827	29.008	16.966	.159	118.174	105.016	222.523	222.523	63.
6	84.172	80.693	20.974	76.942	32.412	28.595	.250	131.832	126.334	252.117	252.117	65.
7	88.752	81.829	21.722	79.794	31.626	29.475	.256	138.200	126.910	259.478	259.478	66.
8	86.693	80.625	21.991	79.060	31.260	29.893	.259	134.743	125.029	253.315	253.315	66.
9	77.488	93.888	12.859	72.219	55.027	17.697	.169	133.222	164.506	291.369	291.369	59.
10	99.589	67.566	13.288	84.571	9.978	17.421	.341	140.163	93.413	237.229	237.229	70.
11	109.400	62.292	12.859	86.873	1.147	17.149	.615	147.679	80.926	235.582	235.582	73.
12	124.286	62.804	9.940	89.123	1.808	10.519	.807	167.205	81.856	256.821	256.821	73.
	1204.341	848.803	171.985	974.070	210.311	218.691	5.910	1738.251	1240.828	2997.930	2997.930	69.

Table B20
Central Plant Energy Utilization Summary—Configuration P-4
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (GBTU)
1	29.968	63.387	9.940	106.281	15.038	16.651	1.123	213.914	108.062	335.769	335.769	58.
2	12.737	64.411	8.978	100.007	28.466	18.623	.622	190.223	112.034	315.114	315.114	56.
3	19.301	63.171	13.288	106.216	10.027	26.154	.819	193.440	103.650	310.533	310.533	59.
4	89.297	61.221	12.859	89.447	63.182	30.927	.300	153.701	107.745	274.999	274.999	55.
5	64.920	65.683	13.288	72.595	155.964	35.623	.269	127.071	130.784	273.519	273.519	48.
6	72.079	79.568	20.974	79.800	150.601	57.290	.388	139.557	152.341	306.840	306.840	49.
7	76.373	80.816	21.722	84.681	163.695	58.551	.395	145.448	152.537	313.768	313.768	50.
8	74.269	79.646	21.991	82.116	167.185	60.229	.402	144.122	152.557	311.916	311.916	49.
9	65.616	92.738	12.859	73.163	90.838	36.852	.273	133.782	188.802	338.038	338.038	47.
10	94.226	67.370	13.288	95.899	61.493	31.774	.352	162.396	118.133	294.913	294.913	55.
11	07.771	62.234	12.859	101.735	18.716	27.652	.472	175.671	102.216	291.007	291.007	58.
12	23.113	62.744	9.940	106.718	13.244	19.578	.706	204.766	106.636	325.132	325.132	57.
	29.668	842.988	171.985	1098.657	938.450	420.904	6.120	1984.089	1535.498	3691.548	3691.548	53.

Table B21
Central Plant Energy Utilization Summary—Configuration P-5
(SI conversion factor: 1 Btu = 1.055 kJ.)

MONTH	TOTAL HEAT ENERGY (GBTU)	TOTAL ELECTR ENERGY (GBTU)	COOLING ENERGY (GBTU)	RCVRED ENERGY (GBTU)	WASTED RCVRABL ENERGY (GBTU)	HEAT EN INPUT COOLING (GBTU)	ELEC EN INPUT COOLING (GBTU)	ENERGY INPUT HEATING (GBTU)	ENERGY INPUT ELECTRC (GBTU)	TOTAL FUEL INPUT (GBTU)	TOTAL ENERGY INPUT (GBTU)	AVERAGE PLANT EFFIC (PERCT)
1	9.545	63.368	9.940	87.828	3.896	15.393	.636	200.557	83.429	296.928	296.928	72.
2	7.793	64.742	8.978	85.309	6.422	14.660	.525	173.743	87.330	272.978	272.978	71.
3	5.615	63.316	13.288	87.688	2.568	22.438	.550	181.867	82.515	277.204	277.204	72.
4	9.743	61.966	12.859	78.689	9.813	24.653	.304	139.781	85.237	237.733	237.733	68.
5	1.874	67.038	13.288	64.927	28.995	29.725	.214	114.871	105.469	235.091	235.091	59.
6	8.455	81.149	20.974	80.719	36.246	47.068	.312	124.860	128.067	267.056	267.056	60.
7	3.234	82.423	21.722	83.087	34.618	48.339	.319	131.297	128.542	274.907	274.907	60.
8	0.749	81.228	21.991	82.430	33.272	48.830	.318	126.948	126.085	267.221	267.221	61.
9	2.764	94.257	12.859	77.931	53.047	30.451	.223	122.368	160.037	297.100	297.100	56.
10	5.633	68.197	13.288	85.621	10.550	25.602	.290	147.954	93.734	255.135	255.135	68.
11	21.283	62.553	12.859	86.140	2.771	22.613	.420	163.475	81.709	257.707	257.707	71.
12	39.801	62.884	9.940	88.354	3.440	15.556	.604	187.608	82.368	282.762	282.762	72.
	58.491	853.120	171.985	988.722	225.638	345.325	4.715	1815.330	1244.520	3221.821	3221.821	66.

APPENDIX C: LIFE-CYCLE COST SUMMARIES

This appendix presents the life-cycle cost summaries for each configuration simulated in the Fort Bragg case study.

Table C1
Central Plant Life-Cycle Cost Summary–Configuration H-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

E Q U I P M E N T T O T A L S				
Steam Boiler	4639.7			
Nominal Size (MBTU)			37.800	
Number Installed			3	
First Cost (K$)		2486.4	2486.4	
Annual Cost (K$)		1975.5	1975.5	
Cyclical Cost (K$)		177.8	177.8	
-----Total----(K$)			4639.7	
1-Stage Absorbtion Chiller	595.1			
Nominal Size (MBTU)			3.600	
Number Installed			1	
First Cost (K$)		120.8	120.8	
Annual Cost (K$)		232.7	232.7	
Cyclical Cost (K$)		241.7	241.7	
-----Total----(K$)			595.1	
Cooling Tower	744.2			
Nominal Size (MBTU)			12.000	
Number Installed			1	
First Cost (K$)		159.9	159.9	
Annual Cost (K$)		59.2	59.2	
Cyclical Cost (K$)		525.1	525.1	
-----Total----(K$)			744.2	
Equipment Total	5979.0			
U T I L I T Y, E N E R G Y	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Elect	48909.5	205.983	56.347	61.900
Boiler	33591.3	388.114	77.745	57.700
Utility, Energy Total	82500.8			

- Life Cycle Cost For 25 Years = 88.4799 (M$)

Table C2
Central Plant Life-Cycle Cost Summary–Configuration H-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

E Q U I P M E N T T O T A L S				
Diesel Engine	15551.7			
Nominal Size (MBTU)			29.000	
Number Installed			3	
First Cost (K$)		12592.6	12592.6	
Annual Cost (K$)		2563.4	2563.4	
Cyclical Cost (K$)		395.7	395.7	
-----Total----(K$)			15551.7	
Steam Boiler	3398.5			
Nominal Size (MBTU)			20.000	
Number Installed			3	
First Cost (K$)		1623.1	1623.1	
Annual Cost (K$)		1739.4	1739.4	
Cyclical Cost (K$)		36.1	36.1	
-----Total----(K$)			3398.5	
1-Stage Absorbtion Chiller	800.9			
Nominal Size (MBTU)			8.000	
Number Installed			1	
First Cost (K$)		206.2	206.2	
Annual Cost (K$)		272.9	272.9	
Cyclical Cost (K$)		321.7	321.7	
-----Total----(K$)			800.9	
Open Centrifugal Chiller	426.3			
Nominal Size (MBTU)			4.000	
Number Installed			1	
First Cost (K$)		117.8	117.8	
Annual Cost (K$)		297.0	297.0	
Cyclical Cost (K$)		11.5	11.5	
-----Total----(K$)			426.3	
Cooling Tower	2920.7			
Nominal Size (MBTU)			12.000	
Number Installed			7	
First Cost (K$)		1119.0	1119.0	
Annual Cost (K$)		414.4	414.4	
Cyclical Cost (K$)		1387.2	1387.2	
-----Total----(K$)			2920.7	
Equipment Total	23098.0			
U T I L I T Y, E N E R G Y	Cost ($K)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	87936.7	674.043	184.578	42.400
Boiler	7690.7	88.859	44.394	57.700
Utility, Energy Total	95627.4			

- Life Cycle Cost For 25 Years = 118.7254 (M$)

Table C3
Central Plant Life-Cycle Cost Summary–Configuration H-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS			
Diesel Engine	15541.3		
Nominal Size (MBTU)			29.000
Number Installed			3
First Cost (K$)		12592.6	12592.6
Annual Cost (K$)		2556.6	2556.6
Cyclical Cost (K$)		392.1	392.1
-----Total----(K$)			15541.3
Steam Boiler	3398.9		
Nominal Size (MBTU)			20.000
Number Installed			3
First Cost (K$)		1623.1	1623.1
Annual Cost (K$)		1739.4	1739.4
Cyclical Cost (K$)		36.5	36.5
-----Total----(K$)			3398.9
1-Stage Absorbtion Chiller	763.4		
Nominal Size (MBTU)			8.000
Number Installed			1
First Cost (K$)		206.2	206.2
Annual Cost (K$)		272.9	272.9
Cyclical Cost (K$)		284.3	284.3
-----Total----(K$)			763.4
Open Centrifugal Chiller	425.1		
Nominal Size (MBTU)			4.000
Number Installed			1
First Cost (K$)		117.8	117.8
Annual Cost (K$)		297.0	297.0
Cyclical Cost (K$)		10.3	10.3
-----Total----(K$)			425.1
Cooling Tower	1850.2		
Nominal Size (MBTU)			24.000
Number Installed			3
First Cost (K$)		763.1	763.1
Annual Cost (K$)		204.0	204.0
Cyclical Cost (K$)		883.1	883.1
-----Total----(K$)			1850.2
Hot Water Tank	40.1		
Nominal Size			12.000
Number Installed			1
First Cost (K$)		27.8	27.8
Annual Cost (K$)		12.3	12.3
Cyclical Cost (K$)		0.0	0.0
-----Total----(K$)			40.1
Cold Water Tank	64.3		
Nominal Size (MBTU)			8.000
Number Installed			1
First Cost (K$)		52.9	52.9
Annual Cost (K$)		11.3	11.3
Cyclical Cost (K$)		0.0	0.0
-----Total----(K$			64.3
Equipment Total	22083.3		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	87245.4	668.744	183.786	42.400
Boiler	7521.9	86.908	44.253	57.700
Utility, Energy Total	94767.3			

- Life Cycle Cost For 25 Years = 116.8506 (M$)

Table C4
Central Plant Life-Cycle Cost Summary—Configuration H-4
(Natural Gas)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS

Gas Turbine	**17106.4**		
Nominal Size (MBTU)			**29.000**
Number Installed			**3**
First Cost (K$)		10074.1	**10074.1**
Annual Cost (K$)		1979.9	1979.9
Cyclical Cost (K$)		5052.4	5052.4
-----Total----(K$)			17106.4
Steam Boiler	3373.7		
Nominal Size (MBTU)			20.000
Number Installed			3
First Cost (K$)		1623.1	1623.1
Annual Cost (K$)		1739.4	1739.4
Cyclical Cost (K$)		11.3	11.3
-----Total----(K$)			3373.7
1-Stage Absorbtion Chiller	823.7		
Nominal Size (MBTU)			8.000
Number Installed			1
First Cost (K$)		206.2	206.2
Annual Cost (K$)		272.9	272.9
Cyclical Cost (K$)		344.6	344.6
-----Total----(K$)			823.7
Open Centrifugal Chiller	415.5		
Nominal Size (MBTU)			4.000
Number Installed			1
First Cost (K$)		117.8	117.8
Annual Cost (K$)		297.0	297.0
Cyclical Cost (K$)		.7	.7
-----Total----(K$)			415.5
Cooling Tower	2160.8		
Nominal Size (MBTU)			12.000
Number Installed			3
First Cost (K$)		479.6	479.6
Annual Cost (K$)		177.6	177.6
Cyclical Cost (K$)		1503.6	1503.6
-----Total----(K$)			2160.8
Equipment Total	23880.1		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	81959.1	946.957	197.595	57.700
Boiler	4123.8	47.646	37.530	57.700
Utility, Energy Total	86082.9			

- **Life Cycle** Cost For 25 **Years** = 109.9630 **(M$)**

Table C5
Central Plant Life-Cycle Cost Summary–Configuration H-4
(Fuel Oil)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS			
Gas Turbine	17106.4		
Nominal Size (MBTU)			29.000
Number Installed			3
First Cost (K$)		10074.1	10074.1
Annual Cost (K$)		1979.9	1979.9
Cyclical Cost (K$)		5052.4	5052.4
-----Total----(K$)			17106.4
Steam Boiler	3373.7		
Nominal Size (MBTU)			20.000
Number Installed			3
First Cost (K$)		1623.1	1623.1
Annual Cost (K$)		1739.4	1739.4
Cyclical Cost (K$)		11.3	11.3
-----Total----(K$)			3373.7
1-Stage Absorbtion Chiller	823.7		
Nominal Size (MBTU)			8.000
Number Installed			1
First Cost (K$)		206.2	206.2
Annual Cost (K$)		272.9	272.9
Cyclical Cost (K$)		344.6	344.6
-----Total----(K$)			823.7
Open Centrifugal Chiller	415.5		
Nominal Size (MBTU)			4.000
Number Installed			1
First Cost (K$)		117.8	117.8
Annual Cost (K$)		297.0	297.0
Cyclical Cost (K$)		.7	.7
-----Total----(K$)			415.5
Cooling Tower	2160.8		
Nominal Size (MBTU)			12.000
Number Installed			3
First Cost (K$)		479.6	479.6
Annual Cost (K$)		177.6	177.6
Cyclical Cost (K$)		1503.6	1503.6
-----Total----(K$)			2160.8
Equipment Total	23880.1		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	123541.4	946.957	197.595	42.400
Boiler	4123.8	47.646	37.530	57.700
Utility, Energy Total	127665.2			

- Life Cycle Cost For 25 Years = 151.5453 (M$)

Table C6
Central Plant Life-Cycle Cost Summary–Configuration A-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

E Q U I P M E N T T O T A L S				
Steam Boiler	7178.1			
Nominal Size (MBTU)			95.000	
Number Installed			3	
First Cost (K$)		4610.2	4610.2	
Annual Cost (K$)		2375.4	2375.4	
Cyclical Cost (K$)		192.6	192.6	
-----Total----(K$)			7178.1	
1-Stage Absorbtion Chiller	1122.6			
Nominal Size (MBTU)			11.740	
Number Installed			2	
First Cost (K$)		533.2	533.2	
Annual Cost (K$)		589.4	589.4	
Cyclical Cost (K$)		0.0	0.0	
-----Total----(K$)			1122.6	
2-Stage Absorbtion Chiller	2334.0			
Nominal Size (MBTU)			9.840	12.000
Number Installed			1	1
First Cost (K$)		738.0	344.5	393.5
Annual Cost (K$)		580.5	284.5	296.0
Cyclical Cost (K$)		1015.5	484.5	531.0
-----Total----(K$)			1113.5	1220.5
Cooling Tower	2424.2			
Nominal Size (MBTU)			12.000	
Number Installed			4	
First Cost (K$)		639.5	639.5	
Annual Cost (K$)		236.8	236.8	
Cyclical Cost (K$)		1547.9	1547.9	
-----Total----(K$)			2424.2	
Equipment Total	13058.9			

U T I L I T Y, E N E R G Y	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Elect	92573.7	407.079	87.758	61.900
Boiler	73863.2	853.416	238.142	57.700
Utility, Energy Total	166436.9			

- Life Cycle Cost For 25 Years = 179.4958 (M$)

Table C7
Central Plant Life-Cycle Cost Summary—Configuration A-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Diesel Engine	20707.2			
Nominal Size (MBTU)			45.000	
Number Installed			3	
First Cost (K$)		16902.9	16902.9	
Annual Cost (K$)		3195.9	3195.9	
Cyclical Cost (K$)		608.3	608.3	
-----Total----(K$)			20707.2	
Steam Boiler	6547.6			
Nominal Size (MBTU)			50.000	30.000
Number Installed			3	1
First Cost (K$)		3700.8	2998.9	709.9
Annual Cost (K$)		2718.0	2089.2	628.8
Cyclical Cost (K$)		120.9	9.1	111.8
-----Total----(K$)			5097.1	1450.5
1-Stage Absorbtion Chiller	1662.6			
Nominal Size (MBTU)			8.000	
Number Installed			2	
First Cost (K$)		412.4	412.4	
Annual Cost (K$)		545.9	545.9	
Cyclical Cost (K$)		704.4	704.4	
-----Total----(K$)			1662.6	
Cooling Tower	3020.1			
Nominal Size (MBTU)			36.000	
Number Installed			3	
First Cost (K$)		1001.3	1001.3	
Annual Cost (K$)		221.2	221.2	
Cyclical Cost (K$)		1797.6	1797.6	
------Total---(K$)			3020.1	
Equipment Total	31937.5			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	168735.0	1293.369	284.459	42.400
Boiler	19016.9	219.721	186.869	57.700
Utility, Energy Total	187751.9			

- Life Cycle Cost For 25 Years = 219.6894 (M$)

Table C8
Central Plant Life-Cycle Cost Summary–Configuration A-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS

Diesel Engine	20695.3			
Nominal Size (MBTU)			45.000	
Number Installed			3	
First Cost (K$)		16902.9	16902.9	
Annual Cost (K$)		3188.1	3188.1	
Cyclical Cost (K$)		604.3	604.3	
-----Total----(K$)			20695.3	
Steam Boiler	6547.8			
Nominal Size (MBTU)			50.000	30.000
Number Installed			3	1
First Cost (K$)		3708.8	2998.9	709.9
Annual Cost (K$)		2718.0	2089.2	628.8
Cyclical Cost (K$)		121.1	8.2	112.8
-----Total----(K$)			5096.3	1451.5
1-Stage Abosrbtion Chiller	1482.5			
Nominal Size (MBTU)			8.000	
Number Installed			2	
First Cost (K$)		412.4	412.4	
Annual Cost (K$)		545.9	545.9	
Cyclical Cost (K$)		524.3	524.3	
-----Total----(K$)			1482.5	
Cooling Tower	2468.7			
Nominal Size (MBTU)			36.000	
Number Installed			3	
First Cost (K$)		1001.3	1001.3	
Annual Cost (K$)		221.2	221.2	
Cyclical Cost (K$)		1246.2	1246.2	
-----Total----(K$)			2468.7	
Hot Water Tank	52.7			
Nominal Size (MBTU)			20.000	
Number Installed			1	
First Cost (K$)		39.1	39.1	
Annual Cost (K$)		13.6	13.6	
Cyclical Cost (K$)		0.0	0.0	
-----Total----(K$)			52.7	
Cold Water Tank	64.3			
Nominal Size (MBTU)			8.000	
Number Installed			1	
First Cost (K$)		52.9	52.9	
Annual Cost (K$)		11.3	11.3	
Cyclical Cost (K$)		0.0	0.0	
-----Total----(K$)			64.3	
Equipment Total	31311.3			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	167271.9	1282.155	284.012	42.400
Boiler	18395.8	212.545	186.929	57.700
Utility, Energy Total	185667.7			

- Life Cycle Cost For 25 Years = 216.9790 (M$)

Table C9
Central Plant Life-Cycle Cost Summary–Configuration A-4
(Natural Gas)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Gas Turbine	24830.3			
Nominal Size (MBTU)			45.000	
Number Installed			3	
First Cost (K$)		13522.3	13522.3	
Annual Cost (K$)		2481.9	2481.9	
Cyclical Cost (K$)		8826.2	8826.2	
-----Total----(K$)			24830.3	
Steam Boiler	6459.9			
Nominal Size (MBTU)			50.000	30.000
Number Installed			3	1
First Cost (K$)		3708.8	2998.9	709.9
Annual Cost (K$)		2718.0	2089.2	628.8
Cyclical Cost (K$)		33.2	0.0	33.2
-----Total----(K$)			5088.0	1371.9
1-Stage Absorbtion Chiller	1662.6			
Nominal Size (MBTU)			8.000	
Number Installed			2	
First Cost (K$)		412.4	412.4	
Annual Cost (K$)		545.9	545.9	
Cyclical Cost (K$)		704.4	704.4	
-----Total----(K$)			1662.6	
Cooling Tower	2379.7			
Nominal Size (MBTU)			36.000	
Number Installed			2	
First Cost (K$)		667.5	667.5	
Annual Cost (K$)		147.5	147.5	
Cyclical Cost (K$)		1564.7	1564.7	
-----Total----(K$)			2379.7	
Equipment Total	35332.6			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	153766.9	1776.625	313.120	57.700
Boiler	9795.2	113.174	178.242	57.700
Utility, Energy Total	163562.1			

- Life Cycle Cost For 25 Years = 198.8947 (M$)

Table C10
Central Plant Life-Cycle Cost Summary—Configuration A-4
(Fuel Oil)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS			
Gas Turbine	24830.3		
Nominal Size (MBTU)			45.000
Number Installed			3
First Cost (K$)		13522.3	13522.3
Annual Cost (K$)		2481.9	2481.9
Cyclical Cost (K$)		8826.2	8826.2
-----Total----(K$)			24830.3
Steam Boiler	6459.9		
Nominal Size (MBTU)			50.000
Number Installed			3
First Cost (K$)		3708.8	2998.9
Annual Cost (K$)		2718.0	2089.2
Cyclical Cost (K$)		33.2	0.0
-----Total----(K$)			5088.0
1-Stage Absorbtion Chiller	1662.6		
Nominal Size (MBTU)			8.000
Number Installed			2
First Cost (K$)		412.4	412.4
Annual Cost (K$)		545.9	545.9
Cyclical Cost (K$)		704.4	704.4
-----Total----(K$)			1662.6
Cooling Tower	2379.7		
Nominal Size (MBTU)			36.000
Number Installed			2
First Cost (K$)		667.5	667.5
Annual Cost (K$)		147.5	147.5
Cyclical Cost (K$)		1564.7	1564.7
-----Total----(K$)			2379.7
Equipment Total	35332.6		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	231781.2	1776.625	313.120	42.400
Boiler	9795.2	113.174	178.242	57.700
Utility, Energy Total	241576.4			

- Life Cycle Cost For 25 Years = 276.9090 (M$)

Table C11
Central Plant Life-Cycle Cost Summary–Configuration C-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

E Q U I P M E N T T O T A L S				
Steam Boiler	5197.7			
Nominal Size (MBTU)			26.000	
Number Installed			4	
First Cost (K$)		2580.0	2580.0	
Annual Cost (K$)		2444.1	2444.1	
Cyclical Cost (K$)		173.6	173.6	
-----Total----(K$)			5197.7	
1-Stage Absorbtion Chiller	590.3			
Nominal Size (MBTU)			12.000	
Number Installed			1	
First Cost (K$)		270.5	270.5	
Annual Cost (K$)		296.0	296.5	
Cyclical Cost (K$)		23.7	23.7	
-----Total----(K$)			590.3	
Equipment Total	5788.0			
U T I L I T Y, E N E R G Y	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Elect	39066.0	166.959	42.207	61.90
Boiler	28178.2	325.571	81.398	57.70
Utility, Energy Total	67244.1			

- Life Cycle Cost For 25 Years = 73.0321 (M$)

Table C12
Central Plant Life-Cycle Cost Summary—Configuration C-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS			
Diesel Engine	13316.0		
Nominal Size (MBTU)			22.000
Number Installed			3
First Cost (K$)		10464.8	10464.8
Annual Cost (K$)		2449.6	2449.6
Cyclical Cost (K$)		401.6	401.6
-----Total----(K$)			13316.0
Steam Boiler	3662.4		
Nominal Size (MBTU)			24.000
Number Installed			3
First Cost (K$)		1834.0	1834.0
Annual Cost (K$)		1804.0	1804.0
Cyclical Cost (K$)		24.5	24.5
-----Total----(K$)			3662.4
1-Stage Absorbtion Chiller	590.3		
Nominal Size (MBTU)			12.000
Number Installed			1
First Cost (K$)		270.5	270.5
Annual Cost (K$)		296.0	296.0
Cyclical Cost (K$)		23.7	23.7
-----Total----(K$)			590.3
Cooling Tower	1864.0		
Nominal Size (MBTU)			12.000
Number Installed			4
First Cost (K$)		639.5	639.5
Annual Cost (K$)		236.8	236.8
Cyclical Cost (K$)		987.8	987.8
-----Total----(K$)			1864.0
Equipment Total	19432.7		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	70937.0	543.739	137.459	42.400
Boiler	5386.1	62.231	56.809	57.700
Utility, Energy Total	76323.1			

- **Life Cycle** Cost For 25 **Years** = 95.7558 (**M$**)

Table C13
Central Plant Life-Cycle Cost Summary–Configuration C-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS

Diesel Engine	13313.6		
Nominal Size (MBTU)			22.000
Number Installed			3
First Cost (K$)		10464.8	10464.8
Annual Cost (K$)		2448.0	2448.0
Cyclical Cost (K$)		400.8	400.8
-----Total----(K$)			13313.6
Steam Boiler	3662.3		
Nominal Size (MBTU)			24.000
Number Installed			3
First Cost (K$)		1834.0	1834.0
Annual Cost (K$)		1804.0	1804.0
Cyclical Cost (K$)		24.4	24.4
-----Total----(K$)			3662.3
1-Stage Absorbtion Chiller	589.8		
Nominal Size (MBTU)			12.000
Number Installed			1
First Cost (K$)		270.5	270.5
Annual Cost (K$)		296.0	296.0
Cyclical Cost (K$)		23.3	23.3
-----Total----(K$)			589.8
Cooling Tower	1788.7		
Nominal Size (MBTU)			12.000
Number Installed			4
First Cost (K$)		639.5	639.5
Annual Cost (K$)		236.8	236.8
Cyclical Cost (K$)		912.4	912.4
-----Total----(K$)			1788.7
Hot Water Tank	32.5		
Nominal Size (MBTU)			8.000
Number Installed			1
First Cost (K$)		21.2	21.2
Annual Cost (K$)		11.3	11.3
Cyclical Cost (K$)		0.0	0.0
-----Total----(K$			32.5
Cold Water Tank	77.6		
Nominal Size (MBTU)			11.000
Number Installed			1
First Cost (K$)		65.5	65.5
Annual Cost (K$)		12.1	12.1
Cyclical Cost (K$)		0.0	0.0
-----Total----(K$)			77.6
Equipment Total	19464.5		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	70798.3	542.676	137.459	42.400
Boiler	5335.6	61.648	56.809	57.700
Utility, Energy Total	76134.0			

- Life Cycle Cost For 25 Years = 95.5985 (M$)

Table C14
Central Plant Life-Cycle Cost Summary–Configuration C-4
(Natural Gas)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS			
Gas Turbine	15542.7		
Nominal Size (MBTU)			22.000
Number Installed			3
First Cost (K$)		8371.9	8371.9
Annual Cost (K$)		1900.9	1900.9
Cyclical Cost (K$)		5269.9	5269.9
-----Total----(K$)			15542.7
Steam Boiler	3643.2		
Nominal Sizé (MBTU)			24.000
Number Installed			3
First Cost (K$)		1834.0	1834.0
Annual Cost (K$)		1804.0	1804.0
Cyclical Cost (K$)		5.3	5.3
-----Total----(K$)			3643.2
1-Stage Absorbtion Chiller	590.3		
Nominal Size (MBTU)			12.000
Number Installed			1
First Cost (K$)		270.5	270.5
Annual Cost (K$)		296.0	296.0
Cyclical Cost (K$)		23.7	23.7
-----Total----(K$)			590.3
Cooling Tower	1917.2		
Nominal Size (MBTU)			12.000
Number Installed			3
First Cost (K$)		479.6	479.6
Annual Cost (K$)		177.6	177.6
Cyclical Cost (K$)		1260.0	1260.0
-----Total----(K$)			1917.2
Equipment Total	21693.5		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	67802.0	763.385	148.724	57.700
Boiler	2097.0	24.229	51.455	57.700
Utility, Energy Total	69899.0			

- Life Cycle Cost For 25 Years = 91.5925 (M$)

Table C15
Central Plant Life-Cycle Cost Summary–Configuration C-4
(Fuel Oil)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS			
Gas Turbine	15542.7		
Nominal Size (MBTU)			22.000
Number Installed			3
First Cost (K$)		8371.9	8371.9
Annual Cost (K$)		1900.9	1900.9
Cyclical Cost (K$)		5269.9	5269.9
-----Total----(K$)			15542.7
Steam Boiler	3643.2		
Nominal Size (MBTU)			24.000
Number Installed			3
First Cost (K$)		1834.0	1834.0
Annual Cost (K$)		1804.0	1804.0
Cyclical Cost (K$)		5.3	5.3
-----Total----(K$)			3643.2
1-Stage Absorbtion Chiller	590.3		
Nominal Size (MBTU)			12.000
Number Installed			1
First Cost (K$)		270.5	270.5
Annual Cost (K$)		296.0	296.0
Cyclical Cost (K$)		23.7	23.7
-----Total----(K$)			590.3
Cooling Tower	1917.2		
Nominal Size (MBTU)			12.000
Number Installed			3
First Cost (K$)		479.6	479.6
Annual Cost (K$)		177.6	177.6
Cyclical Cost (K$)		1260.0	1260.0
-----Total----(K$)			1917.2
Equipment Total	21693.5		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	102201.7	783.385	148.724	42.400
Boiler	2097.0	24.229	51.455	57.700
Utility, Energy Total	104298.7			

- Life Cycle Cost For 25 Years = 125.9921 (M$)

Table C16
Central Plant Life-Cycle Cost Summary—Configuration L-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Steam Boiler	2763.6			
Nominal Size (MBTU)			25.000	37.800
Number Installed			1	1
First Cost (K$)		1457.1	628.3	828.8
Annual Cost (K$)		1264.8	606.2	658.5
Cyclical Cost (K$)		41.8	0.0	41.8
-----Total----(K$)			1234.5	1529.1
Equipment Total	2763.6			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Elect	17625.9	52.398	26.256	61.900
Boiler	7572.7	87.496	41.452	57.700
Utility, Energy Total	25198.7			

- Life Cycle Cost For 25 Years = 27.9623 (M$)

Table C17
Central Plant Life-Cycle Cost Summary–Configuration L-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS			
Diesel Engine	9918.7		
Nominal Size (MBTU)			14.000
Number Installed			3
First Cost (K$)		7730.6	7730.6
Annual Cost (K$)		1947.9	1947.9
Cyclical Cost (K$)		240.1	240.1
-----Total----(K$)			9918.7
Steam Boiler	2052.1		
Nominal Size (MBTU)			16.000
Number Installed			2
First Cost (K$)		931.8	931.8
Annual Cost (K$)		1109.0	1109.0
Cyclical Cost (K$)		11.3	11.3
-----Total----(K$)			2052.1
Cooling Tower	1041.9		
Nominal Size(MBTU)			24.000
Number Installed			1
First Cost (K$)		254.4	254.4
Annual Cost (K$)		68.0	68.0
Cyclical Cost (K$)		719.5	719.5
-----Total----(K$)			1041.9
Equipment Total	13012.6		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	24007.7	184.021	83.827	42.400
Boiler	3101.2	35.831	16.945	57.700
Utility, Energy Total	27108.9			

Table C18
Central Plant Life-Cycle Cost Summary–Configuration L-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS

Diesel Engine	9918.7		
Nominal Size (MBTU)			14.000
Number Installed			3
First Cost (K$)		7730.6	7730.6
Annual Cost (K$)		1947.9	1947.9
Cyclical Cost (K$)		240.1	240.1
-----Total----(K$)			9918.7
Steam Boiler	2052.1		
Nominal Size (MBTU)			16.000
Number Installed			2
First Cost (K$)		931.8	931.8
Annual Cost (K$)		1109.0	1109.0
Cyclical Cost (K$)		11.3	11.3
-----Total----(K$)			2052.1
Cooling Tower	1041.9		
Nominal Size (MBTU)			24.000
Number Installed			1
First Cost (K$)		254.4	254.4
Annual Cost (K$)		68.0	68.0
Cyclical Cost (K$)		719.5	719.5
------Total---(K$)			1041.9
Hot Water Tank	12.7		
Nominal Size (MBTU)			1.000
Number Installed			1
First Cost (K$)		5.3	5.3
Annual Cost (K$)		7.5	7.5
Cyclical Cost (K$)		0.0	0.0
-----Total----(K$)			12.7
Equipment Total	13025.4		

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	24007.7	184.021	83.827	42.400
Boiler	3101.2	35.831	16.945	57.700
Utility, Energy Total	27108.9			

- Life Cycle Cost For 25 Years = 40.1343 (M$)

Table C19
Central Plant Life-Cycle Cost Summary–Configuration L-4
(Natural Gas)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Gas Turbine	10364.6			
Nominal Size (MBTU)			14.000	
Number Installed			3	
First Cost (K$)		6184.5	6184.5	
Annual Cost (K$)		1506.3	1506.3	
Cyclical Cost (K$)		2673.9	2673.9	
-----Total----(K$)			10364.6	
Steam Boiler	2040.7			
Nominal Size (MBTU)			16.000	
Number Installed			2	
First Cost (K$)		931.8	931.8	
Annual Cost (K$)		1109.0	1109.0	
Cyclical Cost (K$)		0.0	0.0	
-----Total----(K$)			2040.7	
Equipment Total	12405.4			
UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	19678.8	227.370	100.726	57.700
Utility, Energy Total	19678.8			

- Life Cycle Cost For 25 Years = 32.0842 (M$)

Table C20
Central Plant Life-Cycle Cost Summary—Configuration L-4
(Fuel Oil)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Gas Turbine	10364.6			
Nominal Size (MBTU)			14.000	
Number Installed			3	
First Cost (K$)		6184.5	6184.5	
Annual Cost (K$)		1506.3	1506.3	
Cyclical Cost (K$)		2673.9	2673.9	
-----Total----(K$)			10364.6	
Steam Boiler	2040.7			
Nominal Size (MBTU)			16.000	
Number Installed			2	
First Cost (K$)		931.8	931.8	
Annual Cost (K$)		1109.0	1109.0	
Cyclical Cost (K$)		0.0	0.0	
-----Total----(K$)			2040.7	
Equipment Total	12405.4			
UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	29663.0	227.370	100.726	42.400
Utility, Energy Total	29663.0			

- Life Cycle Cost For 25 Years = 42.0683 (M$)

Table C21
Central Plant Life-Cycle Cost Summary–Configuration P-1
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Steam Boiler	9392.5			
Nominal Size (MBTU)			1000.000	
Number Installed			1	
First Cost (K$)		7439.2	7439.2	
Annual Cost (K$)		1267.8	1267.8	
Cyclical Cost (K$)		685.5	685.5	
-----Total----(K$)			9392.5	
1-Stage Absorbtion Chiller	2683.8			
Nominal Size (MBTU)			100.000	
Number Installed			1	
First Cost (K$)		1119.9	1119.9	
Annual Cost (K$)		452.3	452.3	
Cyclical Cost (K$)		1111.6	1111.6	
-----Total----(K$)			2683.8	
Equipment Total	12076.3			
UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Elect	182328.5	832.289	163.076	61.900
Boiler	202390.2	2338.419	516.901	57.700
Utility, Energy Total	384718.6			

- Life Cycle Cost For 25 Years = 396.7949 (M$)

Table C22
Central Plant Life-Cycle Cost Summary–Configuration P-2
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Diesel Engine	30669.2			
Nominal Size (MBTU)			85.000	
Number Installed			3	
First Cost (K$)		25863.3	25863.3	
Annual Cost (K$)		3974.9	3974.9	
Cyclical Cost (K$)		811.0	811.0	
-----Total----(K$)			30869.2	
Steam Boiler	7947.4			
Nominal Size (MBTU)			120.000	
Number Installed			3	
First Cost (K$)		5391.4	5391.4	
Annual Cost (K$)		2489.0	2489.0	
Cyclical Cost (K$)		67.1	67.1	
-----Total----(K$)			7947.4	
1-Stage Absorbtion Chiller	2360.2			
Nominal Size (MBTU)			12.000	
Number Installed			3	
First Cost (K$)		811.6	811.6	
Annual Cost (K$)		888.0	888.0	
Cyclical Cost (K$)		660.6	660.6	
-----Total----(K$)			2360.2	
Open Centrifugal Chiller	1154.6			
Nominal Size (MBTU)			12.000	8.000
Number Installed			1	1
First Cost (K$)		433.4	245.9	187.4
Annual Cost (K$)		711.2	370.0	341.2
Cyclical Cost (K$)		10.0	3.6	6.5
-----Total----(K$)			619.5	535.1
Cooling Tower	3814.6			
Nominal Size (MBTU)			100.000	
Number Installed			3	
First Cost (K$)		1985.3	1985.3	
Annual Cost (K$)		271.4	271.4	
Cyclical Cost (K$)		1557.9	1557.9	
------Total---(K$)			3814.6	
Equipment Total	45946.0			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	345474.0	2648.091	539.794	42.400
Boiler	32687.4	377.671	279.864	57.700
Utility, Energy Total	378161.4			

- Life Cycle Cost For 25 Years = 424.1075 (M$)

Table C23
Central Plant Life-Cycle Cost Summary–Configuration P-3
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS

Number Installed				
First Cost (K$)		5391.4	5391.4	
Annual Cost (K$)		2489.0	2489.0	
Cyclical Cost (K$)		67.8	67.8	
-----Total----(K$)			7948.1	
1-Stage Absorbtion Chiller	2146.2			
Nominal Size (MBTU)			12.000	
Number Installed			3	
First Cost (K$)		811.6	811.6	
Annual Cost (K$)		888.0	888.0	
Cyclical Cost (K$)		446.6	446.6	
-----Total----(K$)			2146.2	
Open Centrifugal Chiller	1153.2			
Nominal Size (MBTU)			12.000	8.000
Number Installed			1	1
First Cost (K$)		433.4	245.9	187.4
Annual Cost (K$)		711.2	370.0	341.2
Cyclical Cost (K$)		8.6	2.9	5.8
-----Total----(K$)			618.8	534.4
Cooling Tower	3142.9			
Nominal Size (MBTU)			100.000	
Number Installed			2	
First Cost (K$)		1323.5	1323.5	
Annual Cost (K$)		180.9	180.9	
Cyclical Cost (K$)		1638.4	1638.4	
-----Total----(K$)			3142.9	
Hot Water Tank	67.3			
Nominal Size (MBTU)			31.000	
Number Installed			1	
First Cost (K$)		52.5	52.5	
Annual Cost (K$)		14.8	14.8	
Cyclical Cost (K$)		0.0	0.0	
-----Total----(K$)			67.3	
Cold Water Tank	97.3			
Nominal Size (MBTU)			16.000	
Number Installed			1	
First Cost (K$)		84.2	84.2	
Annual Cost (K$)		13.0	13.0	
Cyclical Cost (K$)		0.0	0.0	
-----Total----(K$)			97.3	
Equipment Total	45215.3			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	342571.6	2625.844	526.055	42.400
Boiler	32204.1	372.066	279.664	57.700
Utility, Energy Total	374775.7			

- Life Cycle Cost For 25 Years = 419.9910 (M$)

Table C24
Central Plant Life-Cycle Cost Summary – Configuration P-4
(Natural Gas)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS

Gas Turbine	36511.4			
Nominal Size (MBTU)			85.000	
Number Installed			3	
First Cost (K$)		20706.6	20706.6	
Annual Cost (K$)		3086.9	3086.9	
Cyclical Cost (K$)		12717.9	12717.9	
-----Total----(K$)			36511.4	
Steam Boiler	7898.5			
Nominal Size (MBTU)			120.000	
Number Installed			3	
First Cost (K$)		5391.4	5391.4	
Annual Cost (K$)		2489.0	2489.0	
Cyclical Cost (K$)		18.2	18.2	
-----Total----(K$)			7898.5	
1-Stage Absorbtion Chiller	2425.9			
Nominal Size (MBTU)			12.000	
Number Installed			3	
First Cost (K$)		811.6	811.6	
Annual Cost (K$)		888.0	888.0	
Cyclical Cost (K$)		726.3	726.3	
-----Total----(K$)			2425.9	
Open Centrifugal Chiller	1146.1			
Nominal Size (MBTU)			12.000	8.000
Number Installed				1
First Cost (K$)		433.4	245.9	187.4
Annual Cost (K$)		711.2	370.0	341.2
Cyclical Cost (K$)		1.6	0.0	1.6
-----Total----(K$)			615.9	530.2
Cooling Tower	2138.4			
Nominal Size (MBTU)			100.000	
Number Installed			1	
First Cost (K$)		661.8	661.8	
Annual Cost (K$)		90.5	90.5	
Cyclical Cost (K$)		1386.2	1386.2	
-----Total----(K$)			2138.4	
Equipment Total	50120.4			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	303214.8	3503.348	585.510	57.700
Boiler	16288.6	188.199	273.220	57.700
Utility, Energy Total	319503.4			

- Life Cycle Cost For 25 Years = 369.6238 (M$)

Table C25
Central Plant Life-Cycle Cost Summary–Configuration P-4
(Fuel Oil)
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS				
Gas Turbine	36511.4			
Nominal Size (MBTU)			85.000	
Number Installed			3	
First Cost (K$)		20706.6	20706.6	
Annual Cost (K$)		3086.9	3086.9	
Cyclical Cost (K$)		12717.9	12717.9	
-----Total----(K$)			36511.4	
Steam Boiler	7898.5			
Nominal Size (MBTU)			120.000	
Number Installed			3	
First Cost (K$)		5391.4	5391.4	
Annual Cost (K$)		2489.0	2489.0	
Cyclical Cost (K$)		18.2	18.2	
-----Total----(K$)			7898.5	
1-Stage Absorbtion Chiller	2425.9			
Nominal Size (MBTU)			12.000	
Number Installed			3	
First Cost (K$)		811.6	811.6	
Annual Cost (K$)		888.0	888.0	
Cyclical Cost (K$)		726.3	726.3	
-----Total----(K$)			2425.9	
Open Centrifugal Chiller	1146.1			
Nominal Size (MBTU)			12.000	8.000
Number Installed			1	1
First Cost (K$)		433.4	245.9	187.4
Annual Cost (K$)		711.2	370.0	341.2
Cyclical Cost (K$)		1.6	0.0	1.6
------Total---(K$)			615.9	530.2
Cooling Tower	2138.4			
Nominal Size (MBTU)			100.000	
Number Installed			1	
First Cost (K$)		661.8	661.8	
Annual Cost (K$)		90.5	90.5	
Cyclical Cost (K$)		1386.2	1386.2	
-----Total----(K$)			2138.4	
Equipment Total	50120.4			

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Gas Tur	457052.2	3503.348	585.510	42.400
Boiler	16288.6	188.199	273.220	57.700
Utility, Energy Total	473340.9			

- Life Cycle Cost For 25 Years = 523.4613 (M$)

Table C26
Central Plant Life-Cycle Cost Summary–Configuration P-5
(SI conversion factor: 1 Btu = 1.055 kJ.)

EQUIPMENT TOTALS					
Diesel Engine	30914.1				
Nominal Size (MBTU)			85.000		
Number Installed			3		
First Cost (K$)		25883.3	25883.3		
Annual Cost (K$)		4131.9	4131.9		
Cyclical Cost (K$)		898.9	898.9		
-----Total----(K$)			30914.1		
Steam Boiler	8000.1				
Nominal Size (MBTU)			120.000		
Number Installed			3		
First Cost (K$)		5391.4	5391.4		
Annual Cost (K$)		2489.0	2489.0		
Cyclical Cost (K$)		119.7	119.7		
-----Total----(K$)			8000.1		
1-Stage Absorbtion Chiller	3001.3				
Nominal Size (MBTU)			12.000	8.000	
Number Installed			1	3	
First Cost (K$)		889.1	270.5	618.5	
Annual Cost (K$)		1114.8	296.0	818.8	
Cyclical Cost (K$)		997.4	23.7	973.7	
-----Total----(K$)			590.3	2411.0	
Open Centrifugal Chiller	425.3				
Nominal Size (MBTU)			4.000		
Number Installed			1		
First Cost (K$)		117.8	117.8		
Annual Cost (K$)		297.0	297.0		
Cyclical Cost (K$)		10.5	10.5		
-----Total----(K$)			425.3		
Cooling Tower	4593.2				
Nominal Size (MBTU)			100.000	28.000	40.000
Number Installed			2	2	1
First Cost (K$)		2245.7	1323.5	564.1	358.2
Annual Cost (K$)		396.5	180.9	140.3	75.3
Cyclical Cost (K$)		1950.9	1950.9	0.0	0.0
-----Total----(K$)			3455.4	704.3	433.5
Equipment Total	46933.9				

UTILITY, ENERGY	Cost (K$)	1-Year Usage (GBTU)	Peak Usage (MBTU)	Cost Escalation Factor
Diesel	346584.0	2656.599	501.435	42.400
Boiler	48920.0	565.222	320.267	57.700
Utility, Energy Total	395504.0			

- Life Cycle Cost For 25 Years = 442.4378 (M$)

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